National Aeronautics and Space Administration

Commercial Orbital Transportation Services

A New Era in Spaceflight

COTS

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Commercial Orbital Transportation Services

A New Era in Spaceflight

On the cover:

Background photo:
The terminator—the line separating the sunlit side of Earth from the side in darkness—marks the changeover between day and night on the ground. By establishing government-industry partnerships, the Commercial Orbital Transportation Services (COTS) program marked a change from the traditional way NASA had worked.

Inset photos, right:
The COTS program supported two U.S. companies in their efforts to design and build transportation systems to carry cargo to low-Earth orbit.

*(**Top photo—**Credit: SpaceX) SpaceX launched its Falcon 9 rocket on May 22, 2012, from Cape Canaveral, Florida.*
*(**Second photo**) Three days later, the company successfully completed the mission that sent its Dragon spacecraft to the Station.*
*(**Third photo—**Credit: NASA/Bill Ingalls) Orbital Sciences Corp. sent its Antares rocket on its test flight on April 21, 2013, from a new launchpad on Virginia's eastern shore. Later that year, the second Antares lifted off with Orbital's cargo capsule,*
*(**Fourth photo**) the Cygnus, that berthed with the ISS on September 29, 2013.*

Both companies successfully proved the capability to deliver cargo to the International Space Station by U.S. commercial companies and began a new era of spaceflight.

ISS photo, center left:
Benefiting from the success of the partnerships is the International Space Station, pictured as seen by the last Space Shuttle crew that visited the orbiting laboratory (July 19, 2011). More photos of the ISS are featured on the first pages of each chapter.

Preface

This document provides a history of the NASA Commercial Orbital Transportation Services (COTS) program executed by the Commercial Crew & Cargo Program Office from 2006 to 2013 at the Johnson Space Center, Houston, Texas. The story was superbly written by Rebecca Hackler in coordination with Rebecca Wright of the JSC History Office. They spent countless hours interviewing dozens of key leaders and participants who shaped the direction and outcome of the program. Their work is greatly appreciated as well as all those who dedicated many years of service to the success of COTS.
It was certainly an honor and privilege for me to have the opportunity to lead this effort and work with such extraordinary and inspirational people. I am hopeful history will show our work over these few short years had long-lasting, transformational effects on the future of commercial spaceflight in America.

Alan Lindenmoyer,
Program Manager

February 2014

For more information on NASA Commercial Crew & Cargo Program, visit www.nasa.gov/cots

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Introduction

In May 2012, the SpaceX Dragon made headlines as it became the first commercial spacecraft to deliver cargo to the International Space Station (ISS). In September 2013, NASA saw a second commercial partner, Orbital Sciences Corp., follow with its own resupply mission to the ISS.

These successful missions represented the fruition of six years of intensive work executed under partnership agreements between NASA and the commercial space community—partnerships that both resulted in the availability of cost-effective cargo transportation services for the Agency, and the advancement of the U.S. commercial space industry.

NASA's support was critical to the companies' success. Said Gwynne E. Shotwell, President of the Space Exploration Technologies Corp. (SpaceX), "We would not be the company that we are today without the support of NASA," continuing, "We'd probably be limping along, trying to change the world, but limping instead of running."[1] Orbital President and CEO David W. Thompson echoed the sentiment as he described how NASA was "very helpful in helping us work through various kinds of problems that came up," concluding that "it's been a great relationship."[2]

These partnerships had their origin in 2005, when NASA Administrator Michael D. Griffin was appointed and, with the support of the presidential administration and Congress, allocated a fixed $500 million contribution from NASA's budget for the instigation of commercial transportation capabilities to low-Earth orbit. The new Commercial Crew & Cargo Program Office (C3PO) at the Johnson Space Center (JSC) in Houston, Texas was charged with the task of "stimulating commercial enterprise in space by asking American entrepreneurs to provide innovative, cost-effective commercial cargo and crew transportation services to the [international] space station."[3]

From 2006 to 2013, under the Commercial Orbital Transportation Services (COTS) program managed by C3PO, NASA acted as an investor and advisor with three different and distinct companies in the space transportation industry to promote the development of U.S. space transportation capabilities on the frontier of human exploration.

If successful, this program promised to support President George W. Bush's 2004 Vision for Space Exploration by filling a gap in resupply services to ISS. New commercial vehicles could take over the task of ferrying cargo to and from low-Earth orbit after the planned 2010 retirement of the Space Shuttle, allowing NASA's new spacecraft, the Orion capsule and Ares rocket, to explore space beyond the Moon and eventually on to Mars.

In addition to allowing NASA to focus on extending humanity's presence in space, COTS would stimulate efforts within the private sector to develop and operate safe, reliable, and cost-effective commercial space transportation systems. Besides supporting ISS, these commercial capabilities could ultimately benefit the U.S. economy by making domestic launch vehicles more competitive in global markets. In turn, lower launch costs could bolster opportunities for other space markets to grow.

One of the first of NASA's commercial partners selected in August 2006, SpaceX, represented the unequivocal success of the COTS model. Shortly after its successful ISS demonstration mission in May 2012, the company quickly provided two critical resupply service missions to the orbiting laboratory under NASA's follow-on Commercial Resupply Services (CRS) contract.

The other partner chosen in the initial selection was less fortunate. NASA terminated its relationship with Rocketplane Kistler (RpK) in October 2007 after the company failed to raise sufficient private funding to continue vehicle development. Orbital Sciences Corp., selected as a COTS partner to replace RpK in February 2008, completed its ISS demonstration mission in the fall of 2013, and joined SpaceX as the second company NASA would rely on for cargo delivery services to ISS.

This report charts the origins and execution of the NASA COTS program, including the elements and people that ultimately made the COTS model a success.

Laying the Foundation

NASA and Industry

Key Concepts

chapter 1

The NASA Commercial Crew & Cargo Program Office (C3PO), formally established in November 2005, represented the culmination of years, even decades, of initiatives to encourage the growth of the private spaceflight sector in the U.S. Although the Commercial Orbital Transportation Services (COTS) government-private sector partnerships established by C3PO represented a new way of doing business in the realm of human spaceflight, such symbiotic relationships have occurred throughout U.S. history.

The year 1869 saw the completion of the first transcontinental railroad that allowed for continuous travel between America's east and west coasts—a project that would not have been possible without the support of government bonds and land grants. In the first half of the 20th century, the 1925 Contract Air Mail Act (more commonly referred to as the Kelly Act) incentivized commercial aviation by allowing the U.S. Post Office to contract with private companies for mail delivery. This eventually led to the use of commercial aircraft for affordable passenger travel, as air travel transitioned from a dangerous, daredevil pastime to a routine operation.

These examples demonstrated the positive benefits of public-private partnerships for advancing U.S. goals and strengthening the American economy through investment in innovative technologies. More than 50 years after Alan B. Shepard's historic spaceflight, visionaries in the aerospace community endeavored to extend the same type of symbiosis to the realm of commercial space transportation.

Commercial companies have been involved in NASA programs as contractors since the Agency's founding in 1958, but it was not until the 1980s that commercial advocates began to more actively seek turnover of routine space operations to the private sector. Multiple NASA programs laid the foundation for the Commercial Orbital Transportation Services (COTS) program, beginning with early efforts to privatize Space Shuttle and Space Station operations. Although not all these programs reached completion, the principles established for successful relationships with the private sector would become pillars of the Agency's mission to develop commercially-available ISS transportation services.

NASA and Industry

Since its founding in 1958, NASA has focused on government-owned and -operated space missions. Throughout the Mercury, Gemini, Apollo, and Space Shuttle programs, the space agency hired contractors to develop launch vehicles and spacecraft. Contractor operations were subject to government insight, defined as "NASA's ability to penetrate" into these companies' "vehicle design, development, test and operations," as well as strict oversight, or "the watchful and responsible care and management" of contractor activity.[4] These early relationships set the pattern for NASA-industry relations for decades to come.

Commercialization in the Space Shuttle Era

When NASA began development of the Space Shuttle, the new vehicle was envisioned as a reliable, low-cost method of launching government and commercial payloads into orbit. The first Shuttle mission, STS-1, occurred on April 12, 1981, shortly after President Ronald Reagan began

President Ronald Reagan visited the Mission Control Center at the Johnson Space Center and spoke with the crew on board Space Shuttle Columbia during the STS-2 mission. During his administration, Reagan supported plans for commercialization of the Space Shuttle, encouraging the private sector to create a viable space transportation industry.

his administration. Hopes for the new system were high with "a sense that a new era was dawning in space, one in which commercialization would play an important part."[5]

This optimism was encouraged by the pro-commercialization space policy Reagan endorsed. During the signing ceremony of the 1984 Commercial Space Launch Act the president stated, "One of the important objectives of my administration has been, and will continue to be, the encouragement of the private sector in commercial space endeavors."[6]

Several startup companies emerged in the 1980s to take advantage of the opportunities they foresaw in this new era of commercial spaceflight, including Orbital Sciences Corp., cofounded by David W. Thompson, and Space Services, Inc., founded by David Hannah and Gary C. Hudson with the expertise of former NASA personnel such as Mercury astronaut Donald K. "Deke" Slayton.[7] In the first few years of Shuttle operations, two companies also proposed to build a fifth, privately-owned Shuttle orbiter to complement the fleet of NASA's four existing vehicles.[8]

In September 1984, NASA Administrator James M. "Jim" Beggs established an Office of Commercial Programs that "encouraged the private sector to become more involved in using space for commercial purposes and increased NASA's efforts to find private-sector uses for NASA-developed technology."[9] The same year, Congress passed the Commercial Space Launch Act that aimed to encourage the growth of the private expendable launch vehicle (ELV) industry. The Office of Commercial Space Transportation (AST) was established in the Department of Transportation to provide the dual role of regulating commercial launches and encouraging the growth of the commercial spaceflight industry.[10]

For many observers in the 1980s, commercial space transportation seemed to be off to a promising start. However in January 1986, a devastating accident resulted in the loss of the Space Shuttle *Challenger*, its crew, and payloads during launch. As a result, many questioned the role of NASA as the primary satellite delivery route to space. Despite the Agency's attempts to keep its customers, President Reagan issued a statement on August 15, 1986, banning commercial payloads on Shuttle. Aerospace companies resumed production of expendable

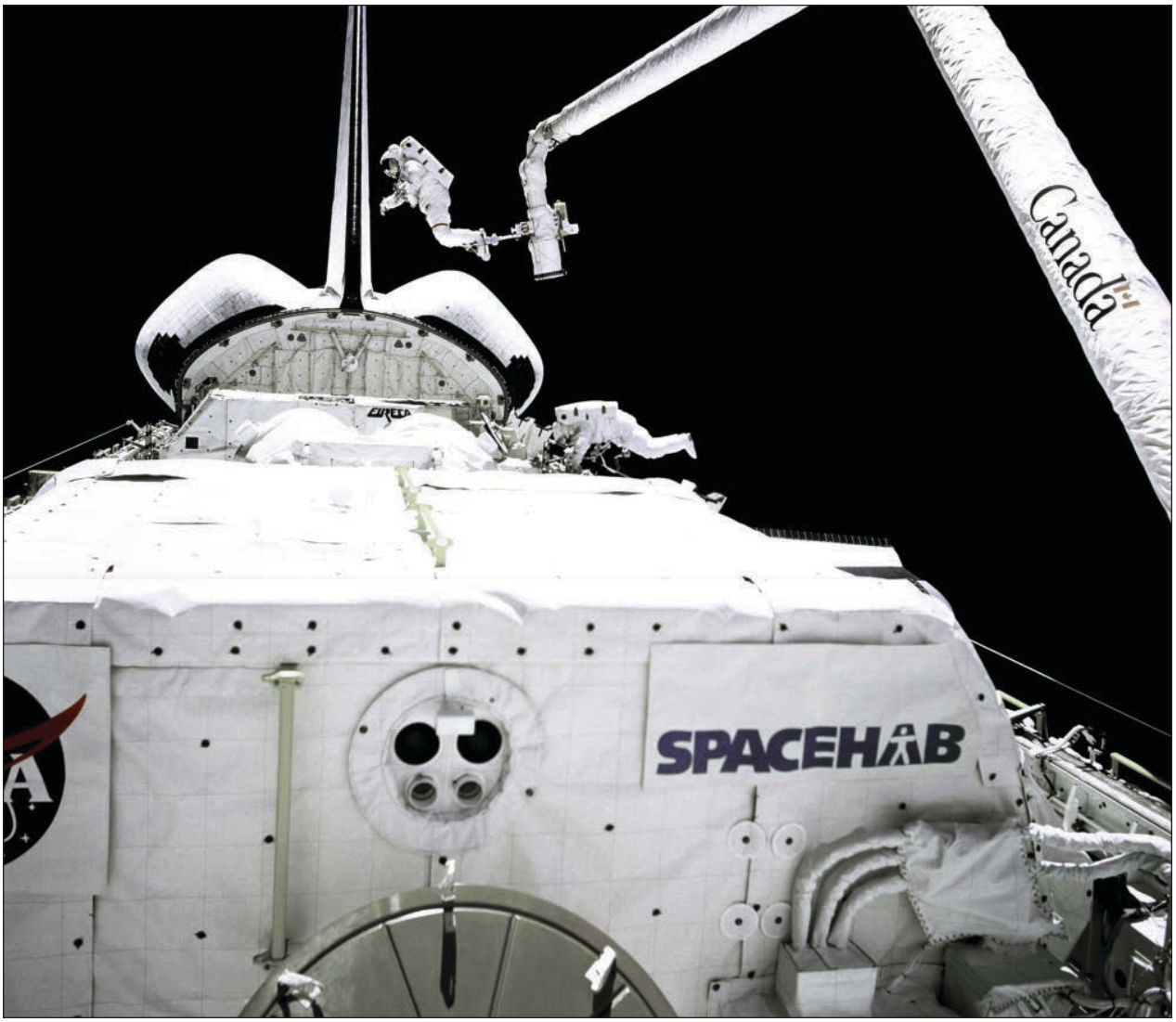
launch vehicles for private customers, aiming to provide cheap and reliable means of getting commercial satellites to orbit.[11]

Early Space Station Commercialization Efforts

The Space Station Program, formally announced by President Reagan on January 25, 1984, offered other potential options for the commercial use of space. Some early concepts for the orbiting habitat included privately-owned modules attached to the core station structure.

A number of proposals from commercial companies offered to house experiments on independent platforms. These included Space Industries, Inc., headed by Maxime A. Faget, former JSC Director of Engineering and lead designer for Space Shuttle and the Mercury capsule. Space Industries proposed to build an Industrial Space Facility (ISF) that would remain in low-Earth orbit and be serviced by visiting Shuttle astronauts as needed. However, the ISF was defeated after a series of controversial Congressional hearings in 1988, as NASA saw the private platform as a direct threat to its own space station program.[12]

Of the multiple commercial space initiatives of the 1980s, only the SPACEHAB pressurized module, in which astronauts could conduct experiments in the Shuttle's payload bay, would fly in space.[13]



SPACEHAB's first module in space provided a laboratory that more than doubled the pressurized workspace for crew experiments. The inaugural flight of this commercially-developed unit was in June 1993 on the Space Shuttle Endeavour as part of the STS-57 mission.

"Faster, Better, Cheaper"

Under Administrator Daniel S. Goldin, who held the position from 1992 to 2001, NASA embarked on a mission to build "faster, better, cheaper" spacecraft. Managers recognized that in order to accomplish this feat they would need to alter customary practices. They based projects such as the Mars Pathfinder on the Lockheed "skunk works" unit that discovered a successful formula for quicker and more efficient aircraft development. Designers reduced the number of people involved and simplified elaborate management oversight structures. Limiting the organization's size helped promote "group cohesion," and team members were given more independent decision-making authority without the burden of outside interference.[14]

Reusable Launch Vehicles

After the breakup of the Soviet Union in 1991, several space transportation companies emerged in response to the new economy created by the end of the Cold War. Names in the U.S. included Pioneer Rocketplane, Kistler Aerospace, and Rotary Rocket, Inc.[15] These companies and their founders would play a significant role in future NASA programs that aimed to increase cooperation with the commercial sector.

Although these new companies aimed to break into the impending satellite communications industry, their projects for low-cost launch systems also had relevant NASA applications. After a decade of Shuttle operations, which turned out to be more expensive and less reliable than originally projected, "the problem of low-cost, routine transportation into space was judged on all sides to be of overriding importance."[16]

In 1996, Lockheed Martin began work on the X-33, a government-industry partnership to lower the costs of sending payloads to space. The rocket plane (illustrated in this artist concept) was to demonstrate the capability of private industry to build and operate reusable launch vehicles for space transportation. The program was cancelled in 2001.

The NASA program to develop second-generation reusable launch vehicles (RLVs, the first-generation RLV being the Space Shuttle) in cooperation with commercial companies in the 1990s included the X-33 and X-34 spaceplanes. For the X-33 project, NASA allowed companies to develop their own concepts, without the government "dictating the design."[17]

Orbital Sciences Corp., a future COTS partner, was an active participant in the X-34 project. Foreshadowing the COTS message of limited oversight, John E. Mansfield, NASA Associate Administrator for Space Access and Technology, claimed, "We are partners with industry and not their managers."[18] Although these vehicles were cancelled mid-development, the X-33 and X-34 projects showed an increasing willingness by NASA to institute a new form of collaboration with industry, especially as budgets grew tighter.

Around the same time NASA also worked to transfer Shuttle operations to the private sector. An independent Space Shuttle management review in February 1995, headed by former Flight Director and JSC Director

Christopher C. Kraft, recommended that responsibility for Shuttle operations be delegated to a consolidated prime contractor. In addition to recommending that NASA remove the restriction on commercial payloads, the report also stated, "Increasing industry involvement in the operation of the space shuttle can be viewed as one of the first steps toward the commercialization of spaceflight."[19]

By the late 1990s, NASA began a more concerted effort to consider options for future space transportation architectures that would allow "assured access to space"—a matter of growing concern for the space agency—including combinations of Shuttle, ELVs, and privately-owned RLVs.[20] In February 1998, NASA Chief Engineer Daniel R. Mulville spoke about engaging with industry to develop commercially viable RLVs. At the time, RLVs in development included, for example, the fully-reusable Roton envisioned by Gary C. Hudson's Rotary Rocket Company, Inc.[21] Mulville believed these next generation systems would develop cargo capability first, before moving to human-rated systems for astronaut transportation.

However, Mulville stressed that companies would determine the best route for their particular business needs: "This is not something we do by ourselves. This is a partnership opportunity. It's a way for us to work with industry." Many of the themes Mulville explored in his remarks would become hallmarks of NASA's cooperation with industry in future years. These included NASA becoming a customer of low-Earth orbit transportation services (as opposed to owner of the vehicle), thereby allowing the space agency to focus on research and development for exploration farther into space. Another theme that would continue to emerge in discussions of the commercialization of low-Earth orbit was the "significant hurdle" for companies to be able to profitably market their services in the private sector.[22]

Credit: Gary C. Hudson

In the late 1990s, reusable launch vehicles were being commercially developed, including the Roton by the Rotary Rocket Company, Inc. The cone-shaped single-stage-to-orbit manned spacecraft featured helicopter rotor blades and an internal cargo bay.

In September 1998, NASA awarded five one-year contracts for the study of a more cost-effective space architecture in order to provide insight into how the Space Shuttle would be utilized in the future. The five companies, including Boeing and Orbital Sciences Corp., suggested concepts such as launch vehicles, in-space transfer vehicles, the type of infrastructure necessary to support these systems, and priorities for investment. The next month, Congress passed the Commercial Space Act of 1998. The Act encouraged the development of commercial services by requiring the government to "acquire space transportation services from United States commercial providers whenever such services are required in the course of its activities."[23]

Decadal Planning Team

In June 1999, Administrator Goldin formed the Decadal Planning Team (DPT), utilizing a core group of experts from across the Agency to undertake long-term strategic planning for NASA's future direction. In the course of the next year, DPT evolved into the NASA Exploration Team (NExT).

For space exploration, DPT/NExT envisioned a "stepping stone" rather than destination-driven approach. This meant that rather than NASA focusing on reaching a single goal, such as Mars, technologies (including power systems and radiation protection) should be developed that allowed for space exploration in general, allowing explorers to methodically venture farther into space.

The NExT annual report for the 2002 fiscal year listed "full commercial use" as one of its main goals. A NExT presentation cited both the 1958 Space Act and the 2000–2003 NASA Strategic Plan in listing the aims to "develop pre-competitive technologies with significant commercial application" and "open the way for U.S. citizens by privatization and commercialization of the space environment."[24] Although Goldin's term ended in November 2001 after nearly 10 years as NASA Administrator, several of the ideas developed under DPT/NExT would form key components of future NASA policy, particularly the 2004 Vision for Space Exploration.

Space Launch Initiative

While DPT undertook its planning studies, in 2000 NASA embarked on the Space Launch Initiative (SLI), administered by the Marshall Space Flight Center in Huntsville, Alabama. The goal of SLI was to reduce the cost of access to space by encouraging the development of second-generation RLVs owned and operated by the private sector. The plan allowed for the advancement of multiple, competing vehicle concepts that would then be methodically narrowed down through a series of milestone reviews. In 2006, the winning concept would proceed to development.[25]

Goldin explained that the "focus [is] on developing an integrated space transportation plan to meet NASA's needs for human and cargo delivery, while seeking synergy with the commercial space sector."[26] It is important to note that unlike later commercial programs, SLI placed a heavy emphasis on NASA-driven and -enforced requirements. In 2002, the Government Accountability Office reported that "NASA believes that much of the SLI program's success is directly related to the implementation of project management controls and appropriate levels of insight," and that the program could not continue until NASA was able to define its requirements for the vehicle systems to be developed.[27]

At this time, resupply to the International Space Station (ISS) continued as a growing concern for NASA. As Program Manager Tommy W. Holloway described: "[ISS] has holes in it that you can drive a truck through, and getting critical spares up to it on time is one of those holes."[28]

Alternate Access to Station

The Alternate Access to Station (AAS) program formed an important part of SLI. In August 2000, AAS distributed a total of $902,000 to four small businesses—Andrews Space, Microcosm Inc., HMX, Inc., and Kistler Aerospace Corp.—to conduct a 90-day study on the feasibility of developing commercial vehicles for contingency resupply to the International Space Station, capable of launching within one week's notice.[29] Kistler, which in February 2006 would merge with Rocketplane Global to form Rocketplane Kistler, later would be awarded COTS money for the development of its K-1 launch system.

Building on that foundation, additional AAS studies in the following months examined aspects such as what sort of space architecture would be needed for commercial launches, risk reduction activities, and how flight demonstrations would be conducted.

In addition to those listed above, some of the 20-plus companies that eventually participated in AAS included Boeing, Lockheed Martin, and Orbital Sciences Corp. Orbital was selected as a COTS partner in February 2008, and it too had formulated early plans for emergency cargo delivery to ISS even before AAS. According to Robert T. "Bob" Richards, Vice President of Human Spaceflight Systems, Orbital had proposed an unsolicited concept called Orb Express that would be able to deliver a few hundred kilograms of cargo, for example a "critical spare," on a few days' notice.[30]

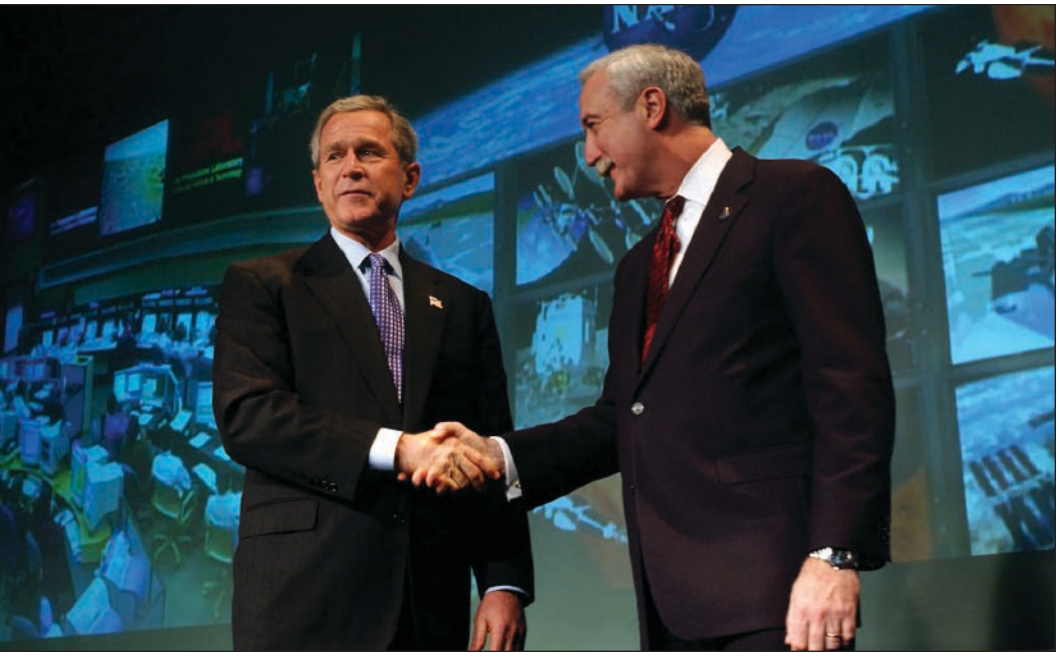
Over the course of the next two years, before the cancellation of SLI in 2002, AAS participants helped develop several of the concepts and vehicles that would be seen in COTS and follow-on commercial initiatives.[31]

Commercialization and the Vision for Space Exploration

The year following the loss of Space Shuttle *Columbia* in February 2003 would prove decisive for the nation's space policy. While Administrator Sean C. O'Keefe led the Agency's efforts to recover from the tragedy of a second Shuttle accident, President George W. Bush announced his Vision for Space Exploration at NASA Headquarters in Washington, DC, on January 14, 2004. This bold vision planned to return humans to the Moon and continue onward to Mars with the development of the Orion crew capsule and Ares launch vehicles, under a new program named Constellation.

And, this new U.S. Exploration Policy included a key place for private spaceflight companies, by directing NASA to "acquire cargo transportation as soon as practical and affordable to support missions to and from the International Space Station." Congress showed its support in the NASA Authorization Act of 2005 by directing the Administrator to "develop a commercialization plan to support the human missions to the Moon and Mars, to support low-Earth orbit activities."[32]

When he entered as the newly-appointed NASA Administrator in April 2005, Michael D. Griffin saw a commercial transportation services program as a broader piece of Constellation: "The commitment was that in the long run, when these companies had learned how to build their rockets and spacecraft, they could have the Space Station cargo market."[33] Once completed, the International Space Station would require regular resupply of life essentials such as water, food, and clothing, not to mention critical hardware and experiments for scientific research. Commercial companies could help provide these crucial resupply services, freeing NASA to pursue the goal of exploration farther into space.



Credit: NASA/Bill Ingalls

President George W. Bush announced the Vision for Space Exploration at NASA Headquarters on January 14, 2004. He directed NASA Administrator Sean O'Keefe (right) and the space agency to develop the plans and the spacecraft to return humans to the Moon and continue onward to Mars. Also included in the new policy was a provision to pursue commercial opportunities for providing transportation and other services supporting the ISS and exploration missions beyond low-Earth orbit.

Ansari X Prize

Further encouraging enthusiasm for the commercial space sector, Scaled Composites, the enterprise of Burt Rutan and Microsoft cofounder Paul Allen, won the $10 million Ansari X Prize on October 4, 2004. The company's SpaceShipOne was the first vehicle to fly a human 100 kilometers into suborbital space, return, and repeat the same feat within two weeks.

For years, commercial space advocates such as James A.M. Muncy had implored Congress to support commercial space initiatives, especially privately-developed transportation to and from ISS. The flight of SpaceShipOne proved that the industry activists who had been clamoring for a chance to develop private space transportation capabilities could in reality develop a reusable manned spacecraft and achieve human spaceflight, independently of NASA.[34]

Multiple commercial space advocates have cited the award of the Ansari X Prize as the catalyst for increasing government support of private space transportation. For these industry supporters, SpaceShipOne seemed to prove the observation that "the high costs of NASA programs are… dictated by the laws of government: Agencies with monopolies are likely to do things the safe, expensive

way," and that more efficient methods of space development were indeed possible.[35]

Concept Exploration and Refinement Study

In September 2004, the Concept Exploration and Refinement (CE&R) study contracts were instituted by Rear Admiral Craig E. Steidle, NASA Associate Administrator for the Exploration Systems Mission Directorate (ESMD). The CE&R funds were awarded to 11 companies "to conduct preliminary concept studies for human lunar exploration and the development of the Orion Crew Exploration Vehicle."[36]

Steidle used his experience developing the Navy Joint Strike Fighter, in which two competitors developed their aircraft independently before having a "fly off" to determine the winner, to apply competition to space vehicle development, aiming for a contest by 2008.[37]

CE&R companies included by-now familiar names such as Boeing, Lockheed Martin, Orbital Sciences Corp., and SpaceHab, Inc.

Gary Hudson, CEO of HMX, Inc., and David Gump established a spinoff organization, the Transformational Space Corp. (t/Space), specifically to bid for the CE&R contracts. t/Space won one of the awards based on its proposal that outlined a space architecture comprised of two spirals of development. First, a commercial taxi would fly astronauts from Earth to orbit (Spiral 1), then astronauts would use in-space transfer vehicles for transportation to and from the Moon (Spiral 2). According to both Hudson and Bretton Alexander, former Vice President for Government Relations at t/Space, the company's work under the CE&R contracts provided the direct template for what later became the COTS program.[38]

Credit: Gary C. Hudson

Gary Hudson and David Gump co-founded the Transformational Space Corp. (t/Space), specifically to bid for the NASA Concept Exploration and Refinement Study contract. (Left to right) Gump, as t/Space president and Hudson serving as Chief Designer worked with Charles Duelfer and Brett Alexander to position the company for commercial spaceflight business.

Around the same time, ESMD conducted a parallel market research survey with 16 companies—including Boeing, Kistler Aerospace, the recently formed Space Exploration Technologies Corp. (SpaceX), and t/Space—regarding the companies' potential to develop low-Earth orbit capabilities and how NASA could favorably engage with them. The responses returned in December 2004 provided guidance on some of the key principles for working with industry that would ultimately manifest themselves in the workings of the Commercial Crew & Cargo Program Office (C3PO).[39]

ISS Commercial Cargo Services

Less than one year before C3PO was established, in the first half of 2005, the ISS Commercial Cargo Services (ICCS) Program administered by the International Space Station Program Office at the Kennedy Space Center in Florida picked up in many ways where AAS had left off. The NASA budget for fiscal year 2005 allocated $140 million toward the effort to achieve the new program's objectives, described as "the purchase of launch, delivery, and earth return services for ISS cargo" in light of eventual Space Shuttle retirement.[40]

As part of ICCS, an industry day was held April 25, 2005, at the Johnson Space Center to review "general technical requirements for

During the final Shuttle mission in July 2011, Astronaut Sandy Magnus (above) facilitated the transfer of approximately 2,700 pounds of food plus more than 9,400 pounds of spare parts, equipment and other supplies from the multi-purpose logistics module to the International Space Station. For years the Space Shuttle had delivered goods to the Expedition crews, the astronauts who resided in space on the ISS. However, the Vision for Space Exploration policy included a scheduled end of the Shuttle Program. This announcement opened the opportunity for commercial companies to transport cargo to the ISS.

commercial cargo transportation services in support of the ISS."[41] Valin B. Thorn, future C3PO Deputy Program Manager, presented the main goals and requirements, outlining how NASA would be acquiring a service to ISS, not the spacecraft itself. Thorn's presentation also reviewed the basic capabilities for such a vehicle, for example the amount of cargo needed for resupply, as well as ISS docking and berthing requirements.[42]

ICCS was the direct antecedent of the Commercial Crew & Cargo Program Office established at JSC in the fall of that year. By February 2006, when the Agency released its fiscal year 2007 budget request, ICCS had been transferred from the ISS Program Office to the Exploration Systems Mission Directorate, where it was renamed Commercial Orbital Transportation Services, or COTS.[43]

Key Concepts

These previous NASA projects and programs showed the evolving nature of NASA's relationships with industry, as the space agency moved towards more cooperative forms of engagement with the private sector. Several of the key concepts from those initiatives were applied to the COTS program, contributing to the successful development of commercially-owned vehicles for ISS resupply.

Transfer Low-Earth Orbit Operations to the Private Sector

Documents from the Space Launch Initiative had noted in 2002 that "U.S. commercial launch vehicles are based largely on decades-old technology," allowing "industry partners" to take over more routine operations in low-Earth orbit while NASA focused "more on science research, technology development and exploration."[44]

NASA initiatives such as SLI and AAS were already looking to move the government away from day-to-day operations and help industry establish more cost-effective space transportation capabilities. AAS specifically designated its study contracts for small businesses, aiming to encourage innovation by working with companies in the private sector that did not have decades of experience with traditional NASA procurement and operations.

Limited Government Investment

For years, advocates of commercial spaceflight had observed that government investment has been used throughout history to promote industry and exploration, reaching as far back as 15th-century monarchs funding voyages across the Atlantic ocean.[45] In a 1999 commercial spaceflight policy seminar, James M. "Jim" Beggs, former NASA Administrator and General Dynamics Corp. Executive Vice President and Director, pointed out that "this country has subsidized transportation for everything over its history. We've subsidized the railroads. We've subsidized the aviation industry. Now, we've got to spend some money and subsidize the space transportation business."[46] The parallels of the transcontinental railroad and Kelly Air Act would become mantras of commercial space supporters.

Also inherent in this idea was that government would be providing a financial investment for the express purpose of advancing the U.S. industry and economy. The Joint Explanatory Statement of the 106th Congress on NASA Authorization commended NASA "for seeking means of reducing our dependence on the Space Shuttle and Russian Soyuz and Progress vehicles for access to ISS" with AAS funds.[47] The theme of reducing U.S. dependence on the Russian vehicles for ISS transportation would emerge throughout the COTS program and into later commercial crew efforts.[48]

Prior to taking the position of NASA Administrator, Griffin had seen the concept of limited government investment in industry projects work in practice. Griffin formerly served as the president of In-Q-Tel, "which in short form could be characterized as the CIA's [Central Intelligence Agency] venture capital fund."[49]

NASA began looking at options for future resupply services to the International Space Station with the retirement of the Space Shuttle set for 2010. By the end of 2005, NASA identified the core operating principles for an innovative program titled Commercial Orbital Transportation Services (COTS). A few months later the initiative was launched with an announcement seeking partners from the U.S. private sector. Pictured above is the ISS in July 2006 as seen by the crew of STS-121.

In-Q-Tel helped finance Keyhole, Inc. to develop the company's geospatial data visualization software—an application that became known as Google Earth after Keyhole was acquired by the internet company in 2004.[50] Griffin's experience using government funds to spur development of technologies which would benefit the intelligence community, and later have widespread commercial application, allowed him to transfer the same principles to the realm of the private spaceflight industry.

Crucially, for this government investment to work, supporters believed that the NASA contribution must constitute only a limited proportion of the total investment; the rest would come from private sources. In fact this was not a new concept. NASA's first Administrator, T. Keith Glennan, envisioned that private industry would provide most of the financing for the research and development of communications satellites in the 1960s, although in practicality the majority of funding was provided by NASA.[51]

According to this model, government involvement would help impart a certain "cachet" that would attract additional outside investors, but the company itself was expected to contribute a significant amount of money to the project.[52] In other words, companies needed to put "skin in the game," a phrase used in the investment community to describe a company's own commitment to its product. This concept described the COTS program philosophy that NASA and the company were partners, each with a stake in the venture.

"Buy a Ticket, Not a Vehicle"

Hand-in-hand with the idea of limited government investment came the important distinction that NASA would not be purchasing the vehicles. Rather, NASA would help selected commercial companies to develop cargo transportation services to low-Earth orbit, which NASA would then be able to buy in the same manner as one would buy a ticket on a commercial airliner.[53]

The Commercial Space Act of 1998 specified that commercial space transportation services be acquired as a commercial item,[54] and the NASA officials who executed the program often compared this concept to handing a package to a courier delivery service. This analogy, previously made during Alternate Access to Station, indicated missions would "demonstrate an alternative access capability for the ISS," after which "funds will be used to purchase services when they become available."[55]

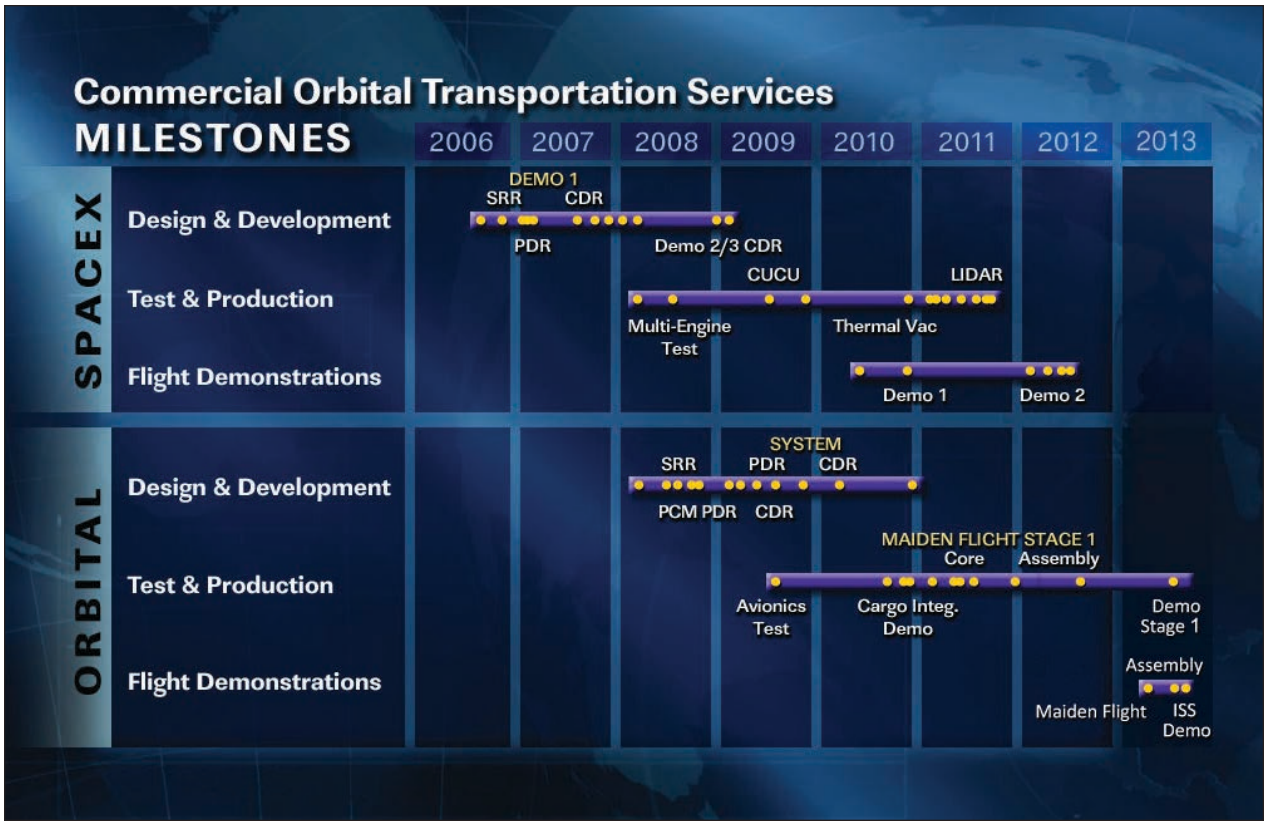
NASA had first been introduced to this "radical" concept in the late 1980s, when pro-commercial forces advocated that NASA buy ELV services, rather than the vehicles themselves.[56] They claimed the government would save 25 percent, owing to reduced costs for vehicle oversight, privileges NASA was reluctant to relinquish. After fierce resistance and battles with the Department of Commerce, NASA began acquiring ELV services in 1988.[57] In 1990, the purchase of commercial launch services was implemented into law with the passage of the Launch Services Purchase Act. The Act required NASA to "purchase launch services for its primary payloads from commercial providers whenever such services are required in the course of its activities."[58]

Now, the same principle would be applied to cargo transportation flights to low-Earth orbit under COTS.

Performance-Based, Fixed-Price Milestones

In NASA's traditional relationships with industry, the government is obligated to pay the additional cost of unforeseen slips in scheduled development. Therefore, in the view of commercial advocates, contractors often have the incentive to do more, less-efficient work, as they know they will not be financially responsible for delays and cost overruns.[59]

The 2004 ESMD market research study proposed the idea of "milestones with actual performance establishing credibility for future funding."[60] In other words, payment would only be guaranteed after the completion of predefined objectives—not on a continual basis as is customary under the system of a cost-plus contract in which companies are awarded a contract for the total cost of the work performed, plus an additional amount for profit. Under this alternative concept, any additional work required to complete the milestones would be the financial responsibility of the company, not the government. Furthermore, these milestones did not necessarily need to be the same for each contractor.



NASA implemented the use of performance-based, fixed-price milestones to invest in its COTS business partners. Funding was issued only after the completion of predefined objectives, and any cost overruns would be the financial responsibility of the company, not the government. This illustration shows actual completion dates. Milestone Schedule charts are included in the Appendix.

Administrator Griffin used the metaphor of a home builder to describe the approach: "I envisioned it as being somewhat like the arrangement when you build an expensive custom home. … [The contractor] gets a small upfront payment to get started, earnest money it might be called, and he gets milestone payments when he completes the foundation and gets the framework up, when he gets the roof on, when he gets the walls in." Griffin added, "But, he doesn't get all the money until he has furnished all the product."[61]

Non-Contract Approach

Even before the first Space Shuttle flight in 1981, NASA had begun to examine alternative options to traditional procurement contracts. In 1979, NASA signed the first Joint Endeavor Agreement with the McDonnell Douglas Astronautics Company to examine the production of pharmaceuticals in space. The space agency did not provide any funds to McDonnell Douglas, but allowed cost-free use of the Space Shuttle for microgravity research experiments.[62]

Alternate Access to Station also recommended new business approaches, reporting to the 53rd International Astronautical Congress that "NASA commercial contracting policies present a perceived barrier" to commercial companies interested in entering the space transportation market.[63] These standard commercial contracting policies—what one commercial advocate called the "suffocating effect of NASA's dominance"—involved cost-plus contract awards governed by the stringent Federal Acquisition Regulation (FAR).[64]

McDonnell Douglas Astronautics Company provided the first commercial experiment for the Shuttle Program – a space continuous flow electrophoresis system (CFES). The company modified laboratory instruments to take advantage of microgravity, and its engineer, Charlie Walker, operated the CFES during spaceflight. Walker (above, STS-41D) served as a payload specialist on three missions before the Space Shuttle Challenger accident that ended commercial Shuttle payloads.

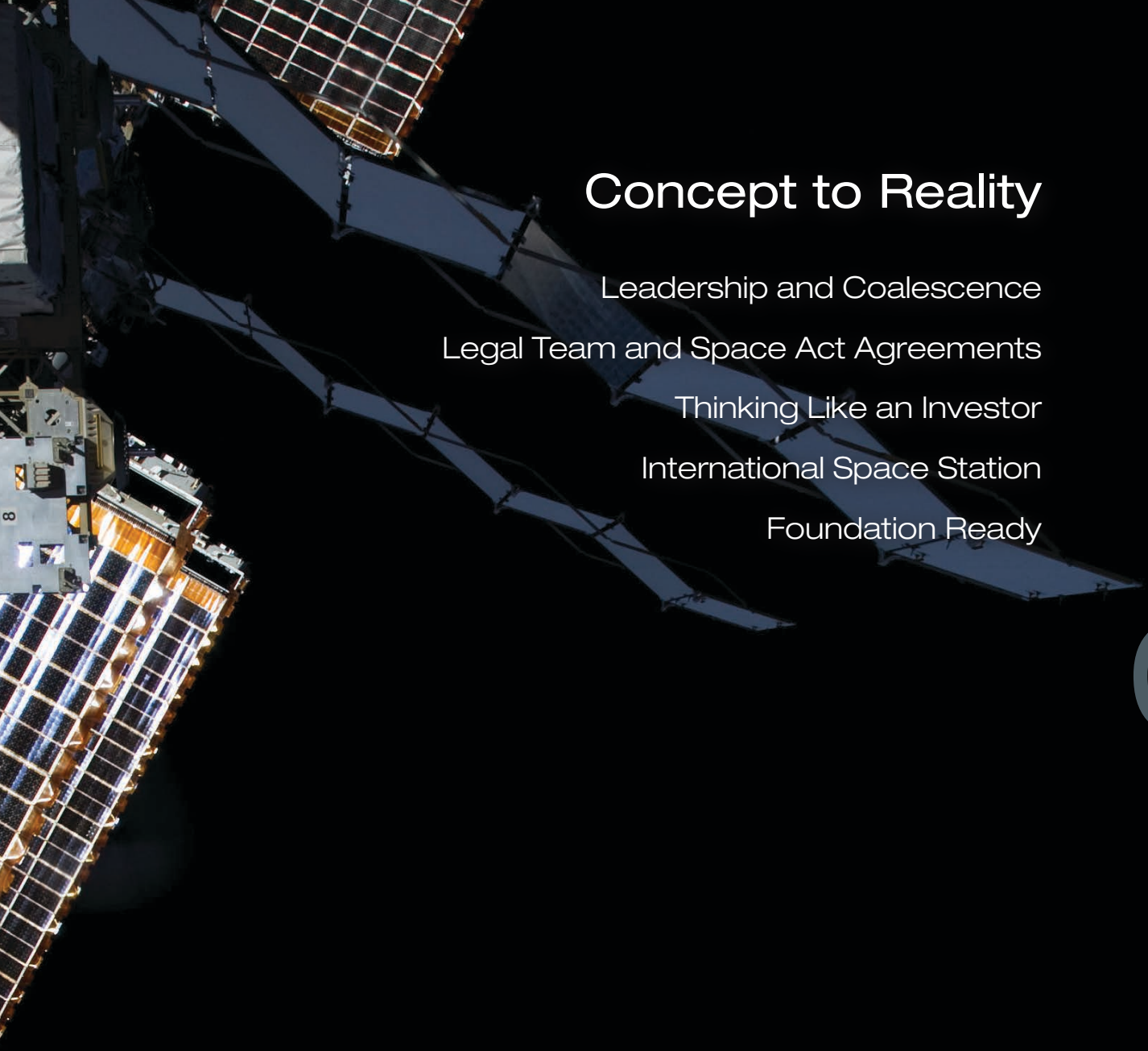
The FAR dictates an intense process to ensure fairness in government acquisitions of goods or services, but "is not known for its efficiency and can be quite cumbersome."[65] Furthermore, smaller startup companies felt some FAR measures left them at a disadvantage. For example, proposers were rated on their past performance, and companies with no history of government contracts could receive a maximum rating of neutral.[66]

Under cost-plus contracts, companies must rigorously follow NASA-imposed requirements and are subject to strict supervision by civil servants, potentially hindering innovation. Designing to specific NASA orders also reduced the possibilities for sales to customers outside the government. To alleviate these constrictions, the 2002 AAS report noted that "disruptive innovations can be a catalyst for change in the industry," adding that "AAS could serve as a change agent for the government-industry relationship."[67]

AAS was cancelled before the program could determine an alternative legal instrument to develop a demonstration or "pathfinder" vehicle with industry, but options under consideration included cooperative agreements and prizes.[68] To address this concern, the 2004 ESMD market research indicated companies preferred the use of NASA's Other Transaction Authority (OTA), granted in the 1958 National Aeronautics and Space Act that founded the Agency, for a more flexible relationship with NASA.[69]

Through a series of promising but incomplete initiatives, NASA adopted several core principles of a new way of doing business with commercial industry. In the fall of 2005, with most of the key concepts in place and a new Administrator, the Agency applied some of these principles to a new venture, the Commercial Orbital Transportation Services initiative.

Having developed the precepts for transferring operations to the private sector—limited government investment, purchasing low-Earth orbit services (not vehicles), and performance based, fixed-price milestones—one major area that remained to be defined was exactly how NASA could use its special Other Transaction Authority. How NASA would apply this OTA would form the cornerstone of the eventual execution of the COTS program.



Concept to Reality

Leadership and Coalescence

Legal Team and Space Act Agreements

Thinking Like an Investor

International Space Station

Foundation Ready

chapter 2

With the key concepts and authorizing policy in place, efforts to promote the development of U.S. commercial space transportation capabilities began to coalesce into an executable program. The new Commercial Orbital Transportation Services (COTS) initiative would not be "business as usual" for the space agency. The acronym itself provided an indication of the mission; "COTS" typically refers to existing "commercial off-the-shelf" items purchased for government use.[70]

NASA planned for its new initiative to be executed in two phases. First, in Phase 1 (what became the COTS program), NASA would help commercial companies develop the capability to transport cargo and crew to low-Earth orbit. Then, in Phase 2 (the future Commercial Resupply Services contracts), NASA would award standard procurement contracts to buy these proven "off-the-shelf" services for delivery of supplies and scientific research experiments to the International Space Station (ISS).

The Agency was looking to future commercial providers to fill the gap in ISS resupply services after the scheduled retirement of the Space Shuttle in 2010. NASA Administrator Michael D. Griffin and several of his top officials at NASA Headquarters in Washington, DC envisioned commercial capabilities as "the primary planned means of supporting ISS transport in the next decade."[71] *If the COTS program proved successful, NASA would have available an alternative method of reaching low-Earth orbit, so the Ares rocket and Orion capsule being developed under the Constellation Program could focus on the goals of returning to the Moon and journeying onward to Mars.*

William H. "Bill" Gerstenmaier, Associate Administrator for the NASA Space Operations Mission Directorate, described COTS as a "high-risk" contingency to see what industry was capable of developing.[72] *Many of the engineers at JSC saw the new commercial initiative as a "side bet" or "back burner" option, especially because it received a relatively limited share of NASA's funding.*[73]

Leadership and Coalescence

After taking the role of NASA Administrator in April 2005, Griffin assigned a fixed $500 million contribution to be allocated over a five-year period, focused on the development of cargo capabilities only. Griffin provided the initial direction for the program, including the guidance to use fixed-price milestone payments, apply limited government investment, preserve company intellectual property, and minimize requirements in order to allow for innovation. The Administrator's guidance also specified that cargo capabilities should be well established before companies progressed to the next step of crew transportation.[74]

NASA Headquarters assigned a team at the Johnson Space Center (JSC) to manage COTS. As Scott J. "Doc" Horowitz, Associate Administrator for the Exploration Systems Mission Directorate (ESMD), said, "If you're going to look at supporting the International Space Station, where do you want to put that work? The International

Space Station is a customer. The people who have experience with supplying things to the International Space Station were at the Johnson Space Center."[75] The new organization at JSC was named the Commercial Crew & Cargo Program Office (C3PO).

Alan J. Lindenmoyer

NASA needed a leader who could manage such an innovative program within the JSC environment of traditional human spaceflight operations. In the fall of 2005, Gerstenmaier, former ISS Program Manager, handpicked Alan J. Lindenmoyer to lead the new endeavor. Gerstenmaier recalled that he looked for a manager with procurement and Space Station experience, who was also capable of pursuing "creative solutions." That is, he sought a leader that was "pretty open, pretty innovative, yet had enough business sense that they could actually pull together an organization and pull that off. That was Alan."[76]

While an undergraduate at Embry-Riddle Aeronautical University, Lindenmoyer had first joined NASA in 1982 as a cooperative education student at the Goddard Space Flight Center in Greenbelt, Maryland. After receiving his Bachelor of Science degree in Aeronautical Studies with Engineering and a commercial/instrument pilot license in 1983, Lindenmoyer completed his Master's in Aerospace Engineering from the University of Maryland in 1986.

In 1987 Lindenmoyer joined NASA Headquarters as a structural dynamics manager for the Space Station Freedom Program. By the time the COTS program was initiated, Lindenmoyer had accumulated nearly 20 years of experience working on the Space Station. After joining JSC in 1990, Lindenmoyer also became known as a contract and configuration management expert, stemming from his experiences in the ISS Program Office as the Assistant Manager for the Vehicle Office, Assistant to the Deputy Program Manager for Technical Development, Manager of the Configuration Management Office, and Technical Integration Manager.[77]

Credit: Don Cohen, NASA APPEL

NASA asked Alan Lindenmoyer to develop and initiate a new era in spaceflight that focused on private industry providing cargo and crew space transportation for the space agency. As Program Manager, Lindenmoyer led a small Commercial Crew & Cargo Program Office (C3PO) team and directed the operations of the Commercial Orbital Transportation Services program from the Johnson Space Center in Houston, Texas.

Lindenmoyer assembled the members of the small C3PO team, who worked diligently to prepare the main elements of the COTS program on a timeline of only a few months.[78] They defined the three goals of C3PO:

1) To implement U.S. Space Exploration policy with investments to stimulate the commercial space industry

2) To facilitate U.S. private industry demonstration of cargo and crew space transportation capabilities with the goal of achieving reliable, cost-effective access to low-Earth orbit

3) To create a market environment in which commercial space transportation services are available to government and private sector customers[79]

Draft COTS Announcement

Even before the new program office was officially incorporated, Lindenmoyer and his team began to identify the core operating principles of the COTS program. On October 5, 2005, Lindenmoyer convened the first "kickoff" meeting of the COTS Procurement Development Team at the Johnson Space Center. NASA Headquarters official Marc G. Timm recalled that the dozen or

so participants contributed ideas as Lindenmoyer "started drawing circles" on a whiteboard "about how we can do this, how we can do that, and how we could actually make this successful."[80] Timm helped C3PO incorporate ISS research and resupply needs into the program. Many of these were based on the Exploration Systems Architecture Study conducted in 2005 to, among other things, "define the top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs."[81]

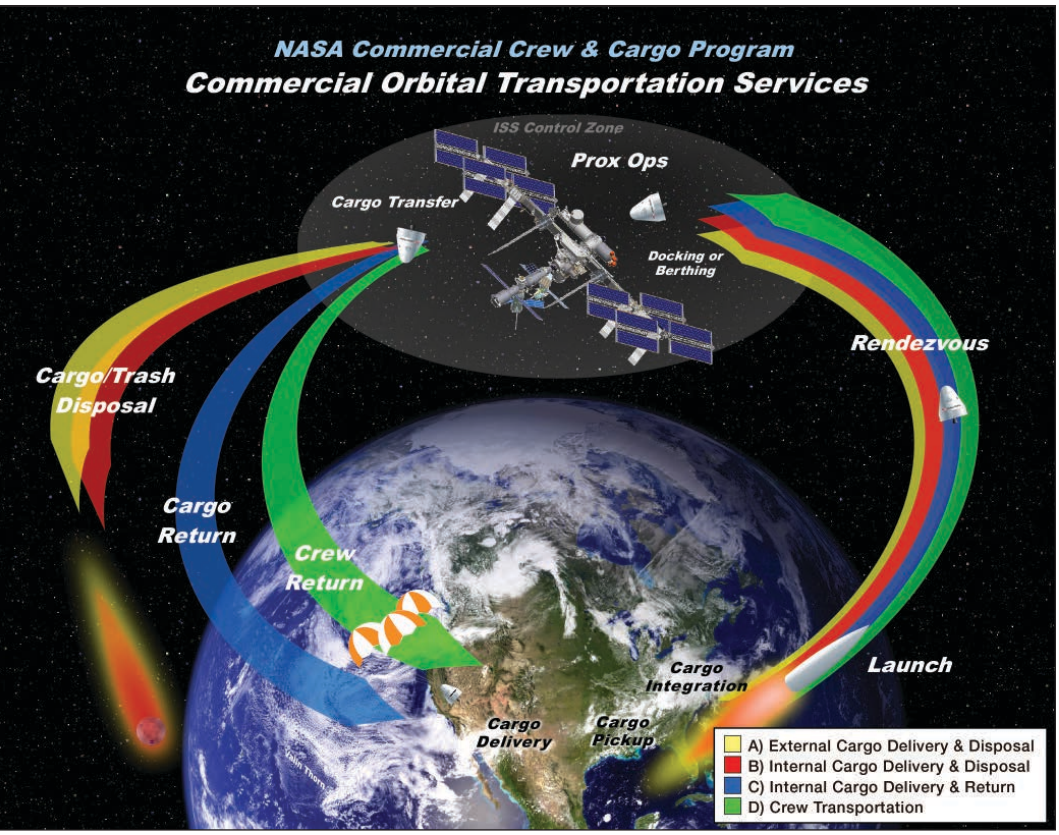
Three weeks later, on October 28, 2005, NASA released a COTS Spaceflight Demonstrations synopsis outlining how "NASA/ JSC plans to solicit proposals from industry for Earth to orbit spaceflight demonstrations of any combination of the following mission capabilities."[82] These capabilities were:

A) External unpressurized cargo delivery and disposal
Capability A "delivers cargo (payloads) that operate directly in the space environment to a LEO [low-Earth orbit] test bed and provides for its safe disposal." This entailed the delivery of equipment to support the test bed structure, such as radiators, batteries, pumps, and other orbital replacement units that allowed the test bed to be serviced and used as an orbiting laboratory over an extended period of time. Unpressurized cargo returned from the test bed is destroyed as it burns in the atmosphere upon a controlled reentry to Earth.

B) Internal pressurized cargo delivery and disposal
Capability B "delivers cargo (payloads) that operates within a volume maintained at normal atmospheric pressure to a LEO test bed and provides for its safe disposal." In addition to the structure itself, the crew also required regular supplies of food, clothing, and equipment, pressurized for delivery inside the habitable modules.

C) Internal pressurized cargo delivery, return and recovery
Capability C "delivers cargo (payloads) that operate within a volume maintained at normal atmospheric pressure to a LEO test bed and provides for its safe return to Earth." This involved the challenging task of returning materials intact through Earth's atmosphere, especially scientific experiments, and other items such as malfunctioning equipment for researchers and engineers to investigate.

D) Crew transportation
Capability D "delivers crew to a LEO test bed and provides for safe return to Earth."[83] While priority number one was to prove cargo capability, the program also included a crew option to be exercised if and when cargo capability had successfully been demonstrated. This future option would require additional NASA funding.



The Commercial Orbital Transportation Services program focused on involving the private sector with crew and cargo delivery to low-Earth orbit. NASA offered four different options to allow companies the flexibility to optimize their unique services and capabilities.

The inclusion of four different options allowed NASA to select a portfolio of companies to meet ISS resupply needs while allowing companies the flexibility to optimize their COTS proposal to their unique business plans and markets.

Not long after the draft announcement was posted, the Commercial Crew & Cargo Program Office hosted an industry day in Houston, a preproposal conference where the COTS approach was unveiled. Lindenmoyer's team outlined the goals and objectives of the program, and held one-on-one meetings with interested companies to get industry feedback. This unique approach set the tone for how the program would actively seek to work with industry as partners, not overseers. The companies' input from the meetings was then collectively assessed by NASA and incorporated into the final Announcement for Proposals released in January 2006.

While this advance notice gave potentially interested companies time to prepare their submissions, Lindenmoyer and the COTS team continued to refine their approach. They examined all elements of a traditional procurement and retained only those elements which they believed contributed to a fair and equitable competition, filtering out those that they felt encouraged bureaucratic slowdown and waste.[84]

Legal Team and Space Act Agreements

The legal process for contract procurement was well established in the 53-part Federal Acquisition Regulation (FAR), but COTS was not to be a traditional procurement—or indeed a procurement at all. Instead of acquiring a good or service, the nascent COTS program would be cooperating and partnering with industry in order to help them develop low-Earth orbit transportation services.

The COTS team needed more than their years of engineering and technical expertise to make the program a success; they relied on expertise in the legal, procurement, and financial fields. In order to make this new type of relationship with commercial partners possible—as true partners, as opposed to contractors—a team of specialists in procurement, intellectual property, and commercial law assembled to design the essential legal framework for the successful execution of the COTS program.

The COTS effort brought together a formidable contingent of experts from both JSC and NASA Headquarters to assemble the essential legal framework that allowed for the successful execution of the COTS program. Many of the NASA attorneys who worked on the program would later describe their work on COTS as a career highlight, enjoying the "energy" that came from creatively working to put together a new type of NASA program.[85]

As the program was quickly but carefully established in late 2005, the legal team stayed in constant contact and communication with their fellow team members, even over the winter holiday break, to prepare the programmatic framework necessary to allow NASA to partner with industry for the development of commercial ISS resupply services.[86]

Together, the group assayed current legislation and policy and determined how NASA could cooperate with industry in such a way as to stimulate the commercial spaceflight industry. NASA's attorneys reviewed the Federal Grant and Cooperative Agreement Act of 1977 (Chiles Act), codified in the *NASA Grant and Cooperative Agreements Handbook*, to ensure the Agency utilized the most appropriate legal instrument to meet the COTS goal of allowing companies to develop their technology without the customary NASA requirements and oversight dictated by standard procurement contracts. They used "cautious innovation," staying within the bounds of existing policy and legislation, particularly the Competition in Contracting Act of 1984, to accomplish the Agency's mission.[87]

Significantly, NASA was not acquiring a good or service for the Agency's direct benefit. Therefore, COTS was not a procurement. Neither was it a grant or a cooperative agreement often used when NASA provides funding to a university for research.

In this case NASA would need to use a Space Act Agreement (SAA), based on NASA's Other Transaction Authority (OTA). The OTA was included in the founding charter of the space agency, the 1958 National Aeronautics and Space Act. It authorized NASA "to enter into and perform such contracts, leases, cooperative agreements, or other transactions as may be necessary in the conduct of its work."[88] NASA was the first federal agency to receive this "catchall" authority, originally included to allow NASA to undertake any agreements necessary to fulfill the Agency's mission in the Cold War Space Race with the Soviet Union.[89] As NASA attorney Amy Xenofos explained, "Any time we do a Space Act Agreement, it's because we can't do it any other way."[90]

Space Act Agreements had previously been used by NASA in their reimbursable and non-reimbursable formats. Reimbursable agreements permitted NASA to collect payment for services provided, while non-reimbursable agreements permitted partnerships without an exchange of funds. However, funded SAAs in which NASA provided payments to a commercial partner constituted a relatively novel way of doing business for the Agency.[91] The legal team's diligent efforts to document the justification of funded SAAs for the COTS program laid a firm foundation for the program's successful execution, as would be proven in the next few years when the legal team was able to successfully defend against legal challenges brought before the Government Accountability Office.

As part of the ongoing effort to carefully distinguish this activity from a FAR-based procurement, the legal team also advised that several elements in the selection process be renamed. In place of a Request for Proposal, COTS issued an Announcement for Proposals. In place of a Source Evaluation Board to select commercial partners, COTS utilized a Participant Evaluation Panel (PEP). The PEP would focus not only on submitted proposals' technical merits, but also the companies' financial credentials that included the question: what was their potential to bring a new commercial off-the-shelf service to market?

Thinking Like an Investor

As observed at a 1999 commercial space policy seminar, "One of the great challenges is taking an R&D [research and development] organization with a lot of history, culture, and institutional structure and trying to make it more entrepreneurial."[92] In order to accomplish their goal, the COTS team of NASA engineers also needed to learn the fundamentals of business and investment.

Dennis A. Stone

Dennis Stone, the COTS Program Integration Manager, had been following the efforts of commercial spaceflight for decades. After receiving dual degrees in physics and electrical engineering from the University of Hawaii at Manoa in 1977, Stone joined McDonnell Douglas to design software for the commercial Payload Assist Module. He then worked at Ford Aerospace and Rockwell International supporting JSC before joining NASA in 1985. In the course of his two decades of work on the Space Station, Stone became increasingly interested in the potential of the private spaceflight sector.

In the early 1990s, Stone pursued his interest in commercialization by studying government-wide lessons learned from buying services and data instead of systems. He also served as ISS Commercialization Working Group Chair prior to the formation of the COTS program.

Credit: C3PO team

Dennis Stone advocated partnerships between NASA and industry to commercialize space. Stone applied his knowledge of the commercial space industry and potential markets while serving as Business Chair during the COTS competitions and as C3PO Integration Manager.

Stone encouraged C3PO to solicit the assistance of a venture capitalist to help the team understand how NASA could fill the role of investor, providing seed money for companies to spur the development of space cargo transportation systems.[93]

Venture Capitalist

On December 21, 2005, JSC issued a Request for Proposal for Venture Capitalist Consulting Services to "support NASA in evaluating the business and management aspects of COTS participants' proposals," and "assist NASA in assessing the business and management performance of selected COTS partners."[94] Chosen to work with NASA was Alan Marty—a former physicist, White House Fellow, and venture capitalist—who had worked with the NASA Ames Research Center in California in the early 2000s to help that center find ways to encourage innovation.[95]

Marty was able to apply both his business acumen and familiarity with government processes and programs to provide invaluable advice to the COTS team. One of the tools Marty placed in the hands of the COTS team was the book *The Innovator's Dilemma* by Clayton M. Christensen.[96] Marty emphasized the book's principle that for innovation to be successful, a spinoff organization must be set apart from its parent organization and all of its entrenched processes and values.[97]

He encouraged the COTS team to examine business plans from the companies, especially their proposed management teams and financing plans. Marty impressed upon the team that the ability to secure financing by the selected company was in fact even more important than its technical ability. This concept contradicted all the prior training NASA engineers had received on selecting contractors.[98]

Marty helped apply Griffin's requirement that COTS partners provide true "skin in the game"; this was vitally important if NASA was to commit to its role as investor of the resulting systems. The designated $500 million for COTS was nowhere near enough to finance an entire space development program, especially after the sum was divided and distributed to multiple companies. For the COTS model to work, the companies needed to be able to secure 1) private capital and 2) private customers, in order to provide 3) truly private services.[99] In other words, too much government involvement would risk "corrupting the market," making this less a commercial enterprise than a government one.[100]

Through close collaboration with what Marty would come to recall fondly as "really good friends," the COTS team worked to upend the traditional NASA contracting culture and encourage the growth of a commercial space transportation industry by acting as a true investor and partner.[101] In addition to learning from Marty, some team members participated in NASA's Business Education Program training course.[102] Reflecting back on his experiences, Marty commended the COTS team for their openness, as they were willing to truly listen and alter the traditions ingrained as career NASA engineers in favor of those more conducive to technology investment.[103]

Credit: Alan Marty

Venture capitalist Alan Marty (right) assisted the C3PO team in evaluating business and management proposals from the potential partners. Marty had worked previously with the NASA Ames Research Center in California to encourage innovation and during the Reagan administration served as a White House Fellow.

Commercial Friendly

The National Aeronautics and Space Act includes the following provision regarding commercial opportunities, present since 1985, the era of Reagan's administration:

"The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration … seek and encourage, to the maximum extent possible, the fullest commercial use of space."[104]

The COTS program aimed specifically to allow small startup ventures the chance to compete in NASA procurements, in addition to the group of large, established contractors that usually dominated major NASA spaceflight contracts. Many of the companies interested in participating in NASA's new program belonged to what was dubbed the NewSpace community of space entrepreneurs and supporters who actively worked to promote the development of commercial spaceflight. Several provisions of the COTS SAAs were deliberately crafted to allow companies of all sizes to participate.

Intellectual Property

With the help of the legal team, the terms of the Space Act Agreement were written to allow companies to retain a great deal more of their intellectual property rights in data and inventions than was permitted with a traditional NASA contract.

In the COTS program, because these partners were not performing work directly for the government, NASA was not entitled to their intellectual property, property and data rights, or proprietary information. Tellingly, Articles 12 and 13 of the SAA on Intellectual Property and Data Rights are the longest in the Agreements.[105]

Creative License

Lindenmoyer and his team were conscious of the fact that the volumes of detailed technical requirements normally levied on NASA contractors could be stifling to innovation. In lieu of strict requirements, the COTS Announcement provided a set of straightforward guidelines to allow companies to provide the needed services to ISS in the manner that worked best for their unique potential. For example, companies pursuing Capabilities B and/or C needed to demonstrate the ability to deliver 8,400 kilograms (about 18,520 pounds) of cargo to low-Earth orbit per year. However, the COTS team made a point not to specify other factors, such as the dimensions of the vehicle, its cargo capacity, the number of flights per year, and sites for launch and operations.[106]

Under the Space Act Agreement, companies were allowed and even encouraged to develop vehicles and capabilities that could be marketed to potential customers outside the government, whereas the traditional contract approach resulted in systems that would be owned and operated solely by NASA. "We wanted companies to be able to freely innovate, to take maximum advantage of whatever concept they had, whatever strengths they had in their company that could bring this capability to market with the minimum constraints possible," said Lindenmoyer.[107]

Committed Partnership

To further encourage private investment, the Space Act Agreement provided very limited provisions for termination by NASA. Traditional NASA contracts often contain a termination for convenience clause, which allows the government to end the agreement for any reason it chooses. The COTS Space Act Agreements, however, could be terminated under Article 17 only in the case of A) Mutual Consent, B) Failure to Perform [i.e., the company's failure to meet the agreed-to milestones], or C) Reasons Beyond NASA's Control that included national emergencies, declarations of war, or "failure of Congress to appropriate sufficient funding."[108]

In contrast to a traditional cost-plus contract, COTS partners would only receive payment from NASA after they had completed established milestones, meaning the company, not NASA, would be responsible for any cost overruns. Financial milestones were set early in the program, so if a company failed to meet the required amount of private financing, the Agreement could be terminated early before NASA had invested a more substantial sum of money into the project. This allowed for sharing of financial risk, and gave NASA an "exit ramp" in case the partner was unable to raise its share of the capital.[109] Such a scenario was not only possible, but indeed became a reality after the Round 1 COTS competition.

International Space Station

The other key component of the COTS program involved the International Space Station itself. The question of whether or not to use the ISS as the orbital test bed for companies' demonstrations to low-Earth orbit did result in a minor legal dilemma. On the one hand, the COTS program aimed to allow for as much creativity in design as possible, without the imposition of detailed specifications. On the other hand, companies with sights on a demonstration mission to the ISS had to contend with the Station Program's set of strict, predefined visiting vehicle requirements for rendezvous, proximity operations, and berthing or docking. The inclusion of ISS requirements would have violated both the spirit and the letter of the COTS model of minimal requirements.

Ultimately, companies were presented with the option of using the International Space Station to demonstrate the capability to deliver cargo to a vehicle in low-Earth orbit. Consequently, if that option were chosen, companies that elected to use the Station as an orbital test bed would be obligated to meet ISS requirements. Although the majority of bidders ultimately did propose to visit the ISS in order to better position themselves to compete for a future services contract, it was important that this was not levied as a strict requirement.[110]

For those that chose to demonstrate to a test bed other than the ISS, the draft SAA included an alternative set of language. As part of the proposed business plan, submissions needed to include an Operational Readiness Plan that explained how the company planned "to offer operational services" to ISS.[111]

Vehicles visiting the International Space Station follow strict requirements for rendezvous, proximity operations, and berthing or docking. Adhering to these requirements was the Japan Aerospace Exploration Agency for its HTV, (pictured above), a large unmanned capacity cargo vehicle that first transferred supplies to the ISS in 2009. The vehicle's nickname, Kounotori, is the Japanese word for "white stork," symbolic of the important cargo it ferries to the astronauts living in low-Earth orbit.

With that legal technicality resolved, the next issue presented itself in the form of the ISS visiting vehicle requirements. Hundreds of pages with thousands of requirements had evolved over the decades-long history of ISS development and operations, in particular integration with the Russian Soyuz and Progress spacecraft, the European Space Agency's Automated Transfer Vehicle (ATV), and the Japan Aerospace Exploration Agency's H-II Transfer Vehicle (HTV). How could startup companies, without the detailed background knowledge of ISS visiting vehicle integration, have a fair chance in the competition? The answer lay in the expertise of Lindenmoyer's chosen Deputy Program Manager, Valin B. Thorn.

Valin B. Thorn

C3PO Deputy Manager Valin B. Thorn graduated with a Bachelor of Science Degree with honors from Arizona State University, and also attained a commercial pilot's license with instrument and multiengine ratings. As a member of the Experimental Aircraft Association, Thorn had seen first-hand what a small team of engineers could accomplish, and strongly believed in the potential of commercial spaceflight endeavors. Thorn came to C3PO with some 25 years of aerospace experience, with 15 of those focused on ISS. Having led ISS systems engineering and integration teams such as Vehicle Integrated Performance and Resources (VIPER) and Strategic Planning and Requirements (SABER), Thorn possessed a broad-based knowledge of how different components of the ISS worked together.[112]

Credit: C3PO team

C3PO Deputy Manager Valin Thorn utilized his knowledge and experiences gained from 25 years of working in the aerospace field and the ISS Program to help guide the new Commercial Crew & Cargo Program. As part of his contributions, Thorn led the effort to consolidate crucial integration information in an easy-to-follow document for potential industry partners interested in flying their vehicles to the International Space Station Program.

Crucially for the COTS program, this knowledge also encompassed the requirements for integrating a new visiting vehicle into the ISS architecture. Already in April 2005 Thorn had presented "ISS Commercial Cargo Services: Requirements and Constraints Summary" at the industry day at JSC for companies interested in providing commercial cargo services to the ISS.[113]

Interface Requirements Document

Instead of overwhelming companies with multiple volumes of documentation, Thorn and a small team of support contractors synthesized and distilled the most crucial information from existing Interface Control Documents for the ATV and HTV into the approximately 130-page COTS Integration and Interface Requirements Document (IIRD).

Only a few days after the COTS Announcement, on January 25, 2006, Thorn's team released the IIRD in an easy-to-follow format. The document provided the companies an introduction and overview of what to expect regarding working with the ISS while preparing proposals.[114]

Consistent with the COTS Model, the IIRD introduction included the statement that "COTS providers are given flexibility to propose rationale back to NASA for choosing to modify or not meet a stated requirement."[115] Applicants were encouraged to find innovative, creative ways of doing business, while still operating safely and fulfilling the mission to low-Earth orbit; the requirements were not important in and of themselves, but for the ultimate purpose of providing commercial cargo transportation services to the ISS.

Foundation Ready

By January 18, 2006, NASA had released the program's Announcement for Proposals with the terms of the competition. Included in this Announcement was a draft Space Act Agreement friendly to commercial interests, allowing a degree of flexibility rarely seen in a government contract. In the span of a few months, the unique assemblage of engineers, lawyers, procurement specialists, and a venture capitalist that comprised the COTS team had succeeded in putting together the key documents for NASA's new way of doing business, transitioning a set of unproven concepts into the reality of the Commercial Crew & Cargo Program.

As Lindenmoyer observed, "The Space Act [Agreement] itself was so commercial friendly, companies loved this. They knew this was not business as usual. They knew this was going to be a different way of doing business, and were very supportive of it and complimentary of NASA for developing this new way of investing."[116]

The commercial space transportation industry was one step closer to its goal of delivering cargo to the International Space Station. When they embarked on this new, disruptive venture, some members of the COTS team expressed unflagging confidence that the program would work, while others at NASA were less certain. One thing, however, was clear: the JSC team, with help and guidance from NASA Headquarters and outside experts, was going to give it a try.

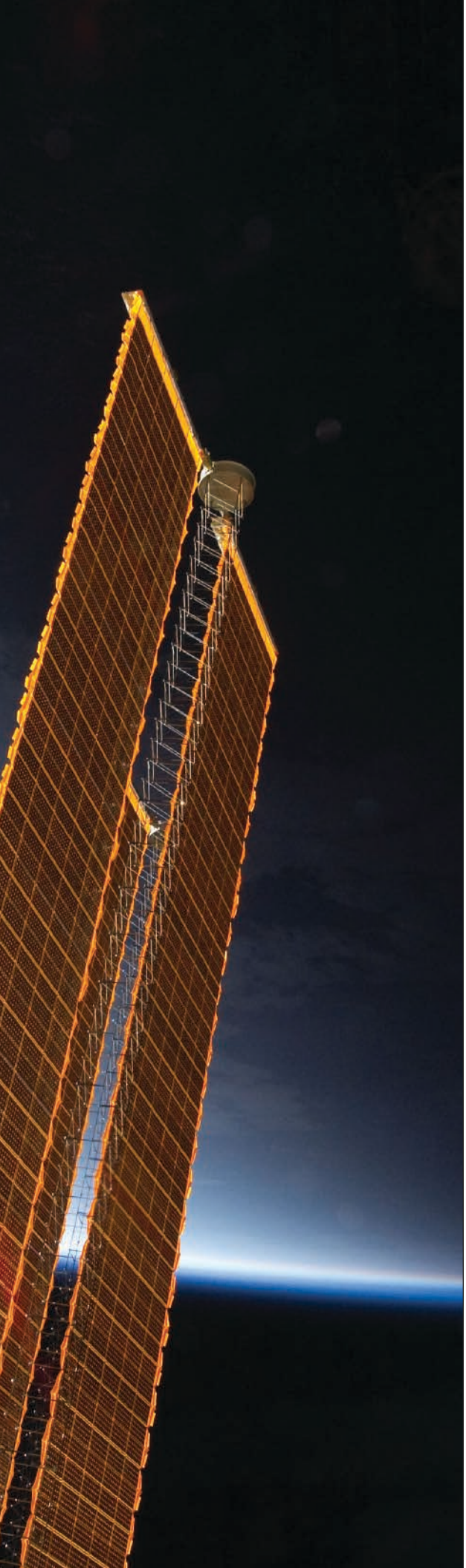
Competition

Round 1

Round 2

Unfunded Space Act Agreements

chapter 3



The first COTS competition took place in 2006, as the Commercial Crew & Cargo Program Office (C3PO) embarked on the operational phase of NASA's new way of doing business with the private space industry.

Round 1

Round 1 Announcement

NASA released the Commercial Orbital Transportation Services (COTS) Announcement for Proposals on January 18, 2006.[117] After a brief introduction explaining the COTS background and philosophy, the Announcement described NASA's intent to award funded Space Act Agreements (SAAs) for spaceflight demonstrations to low-Earth orbit of the following capabilities:

A: External cargo delivery and disposal

B: Internal cargo delivery and disposal

C: Internal cargo delivery and return

D: Crew transportation

The Announcement also included several other key provisions. First, because the COTS program aimed to develop a U.S. capability to low-Earth orbit, the Announcement specified that the company be "more than 50 percent owned by United States nationals," or provide substantial evidence of its commitment to U.S. interests.[118] Companies, of course, needed to comply with U.S. laws such as commercial space launch acts, and the Iran and Syria Nonproliferation Act.[119]

Second, the Announcement specified the format and the page count for the prescribed proposal contents, limiting the submission to 65 to 90 pages depending on which capabilities were proposed. The COTS selection team viewed this abbreviated proposal as a first step before conducting the decisive face-to-face due diligence. Members weighed this so-called "kick the tires" stage as a venture capitalist would, using it as a prescreening mechanism usually not permitted by FAR-based procurements.[120]

According to C3PO Deputy Manager Valin B. Thorn, many of the companies that submitted proposals actually found that preparing these consolidated submissions, limited to the most important points, was actually more difficult than including every possible element in detail. However, having a concise and to-the-point proposal made it easier for evaluators to determine its merit and still provided sufficient information to differentiate between companies.[121]

Finally, the draft Space Act Agreement found in the Announcement's appendix provided the legal basis for key provisions such as intellectual property rights. Companies were allowed to propose alterations for specific needs and to identify their unique milestones with requested NASA funding for each.

NASA attorney Amy V. Xenofos reported that NASA had little idea of what kind of proposals to expect from companies interested in NASA's new way of doing business.[122] By not imposing technical requirements, the Announcement allowed companies to submit a creative range of possibilities. Despite this

Credit: NASA/Bill Ingalls

Soon after becoming NASA Administrator, Mike Griffin (seated left) assigned a fixed $500 million allocation over a five-year period to focus on commercially-developed cargo transportation capabilities. Responsible for the new program was Scott "Doc" Horowitz (right), NASA's Associate Administrator for the Exploration Systems Mission Directorate. He served as the Selection Authority for the COTS program's first round of Space Act Agreements.

flexibility, C3PO Program Integration Manager Dennis A. Stone stressed that a detailed evaluation plan was established before proposals arrived and was "strictly followed."[123]

Participant Evaluation Panel

Just as the legal team endeavored to help NASA meet its mission through the institution of funded SAAs, the procurement team contributed their knowledge of fair acquisition and objective selection practices and processes that had evolved over decades of NASA-contractor relations.[124] The Participant Evaluation Panel (PEP) was set up to review the proposals, and carried over many principles and procedures from the traditional government procurement Source Evaluation Board.

The variations introduced by COTS allowed the PEP to preserve the program's goals of not imposing overly strict requirements, and to "level the playing field" for startup companies with little or no history of government contracts. The panel understood the importance of examining the proposal's technical merit—important for spacefaring vehicles aiming to service the International Space Station—as well as the potential partner's viability as a commercial entity.

C3PO Manager Alan Lindenmoyer chaired the Participant Evaluation Panel, overseeing the efforts of the three PEP committees: technical, business, and financial. The committees drew on teams of advisors and technical experts, but only six members were granted a vote: the PEP Chairperson, Technical Committee Chair, Business Committee Chair, Financial Committee Chair, Safety and Mission Assurance Senior Representative, and a Contracting Officer-Agreements Officer.[125]

Thorn led the technical committee, applying his years of ISS integration experience to determine the feasibility of the plans to reach ISS. His team included representatives from multiple NASA centers and a variety of disciplines. Bruce A. Manners, who would later serve as a COTS Project Executive, was one of the nine members of this team.

Stone was able to apply his knowledge of the commercial space industry and potential markets in his role as chairman of the six-member business committee that also included venture capitalist Alan Marty. The business committee evaluated the company's potential to "operate a sustained, profitable entity that may supply the market of space transportation services to NASA and other customers," and examined aspects such as the experience of each company's management team and financial plans.[126]

The small, three-member financial committee, chaired by Vickie H. Gutierrez, evaluated the reliability of cost estimates and the requested amount of funding from NASA. Mark D. Erminger served as the senior representative from the Office of Safety and Mission Assurance, and would continue as the designated Safety and Mission Assurance Officer for the majority of the COTS program.

Proposals

In total, NASA received 21 proposals from 20 companies "across the full spectrum of the industry" by the March 3, 2006, deadline.[127] Scott J. "Doc" Horowitz, the Selection Authority at NASA Headquarters for the COTS Space Act Agreements, described the proposals as ranging from "somebody [who] was going to build a rocket engine in their garage" to some that offered to conduct a study without building any physical hardware, and "everything in between."[128]

The companies ranged from major names in the aerospace industry such as The Boeing Company and Lockheed Martin Corp. (which submitted two proposals, one for all four capabilities, and one for only Capability B), to established but smaller-scale launch companies such as Orbital Sciences Corp., to little-known startups such as PanAero Inc. and Venturer Aerospace.[129] Some proposals included vehicles that resembled the soon-to-be-retired Space Shuttle, while other designs were similar to the capsule spacecraft of the Apollo Program. Multiple proposals relied on heritage concepts and hardware, while others advanced new technology such as non-water landings on airbags.

Before the PEP conducted a more in-depth analysis, the Contracting Officer-Agreements Officer was responsible for an initial review of the proposals. NASA Contract Specialist James W. Bailey determined whether or not the submissions were "consistent with Announcement's instructions" and "otherwise acceptable for purposes of evaluation."[130]

After passing this preliminary compliance review, the PEP found that 18 submissions met the Step 1 Initial Screening criteria of feasibility, relevancy, and affordability for commercial resupply services to ISS within the desired timeframe.[131] The PEP evaluated these proposals on 1) how well the plan, if implemented, would meet the goals of the Announcement, and 2) confidence that the plan could be implemented. In keeping with the goal of providing opportunities for both startups and established aerospace contractors, the PEP did not consider past performance under government contracts in the decision-making process. Evaluators did, however, examine the past experience of company leaders, as well as its business plans and management structures.[132]

Instead of numerically scoring the proposals as in a traditional Source Evaluation Board, submissions were assigned levels of confidence based on how convinced NASA was that the company could execute its proposed plan, from "very high level of confidence" to "very low level of confidence." These levels were based on the degree of strengths and weaknesses established in each of the three committees' findings.

The PEP assigned a color to each level of confidence (blue for very high, green for high, white for moderate, yellow for low, and red for very low). A matrix provided a visual summary of key proposal attributes the PEP took into account: capabilities covered, the color ratings, potential markets, amount requested from NASA, and the choice of orbital test bed (ISS or other).[133]

Selection

NASA made the decision to select two companies in order to allow for competition, while at the same time being able to distribute sufficient amounts of money to each partner for their development programs.[134] Only 3 percent of the COTS budget was set aside for operating funds, leaving $485 million total for distribution between the selected partners.

Prior to the final decision, the PEP sorted the findings into candidate portfolios, i.e., combinations of finalists that listed a variety of options to fit both the needed capabilities for ISS resupply and the COTS budget. According to Stone, "This was a most significant departure from standard SEB practices."[135]

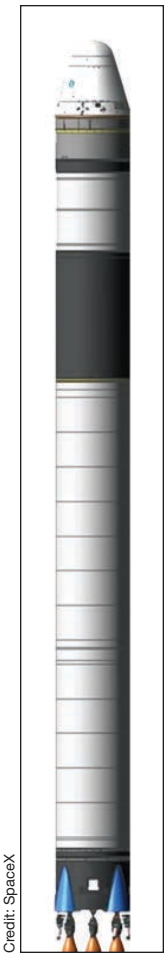
The PEP then reported its results to the ultimate Selection Authority, the Associate Administrator for ESMD at NASA Headquarters, and his executive council composed of various internal and external stakeholders. Advisors included NASA Headquarters representatives from the Office of Safety and Mission Assurance, General Counsel, Procurement, and Engineering, as well as the program offices of ISS and Constellation. George C. Nield

represented the Federal Aviation Administration Office of Commercial Space Transportation, and Selection Authority Horowitz also brought in Byron M. Allen as an independent business consultant.[136]

Horowitz took various factors into account in his decision, including the total cost, capabilities covered, the color-coded rating, both business and technical risk, and potential markets for the capabilities developed.[137] Based on PEP input, Horowitz selected six finalists (listed in alphabetical order): Andrews Space Corp., Rocketplane Kistler Limited Inc. (RpK), SpaceDev, Inc., Space Exploration Technologies Corp. (SpaceX), SpaceHab Inc., and the Transformational Space Corp. (t/Space). Significantly, none of the selected companies represented the major names in the industry with decades of government contract experience, but rather exemplified the emerging NewSpace community.[138]

These six finalists then underwent a series of intensive due diligence meetings. PEP members visited facilities and spoke to management personnel "face to face, eyeball to eyeball," to better understand company operations, particularly the qualifications of the management team and the proposed funding plans.[139]

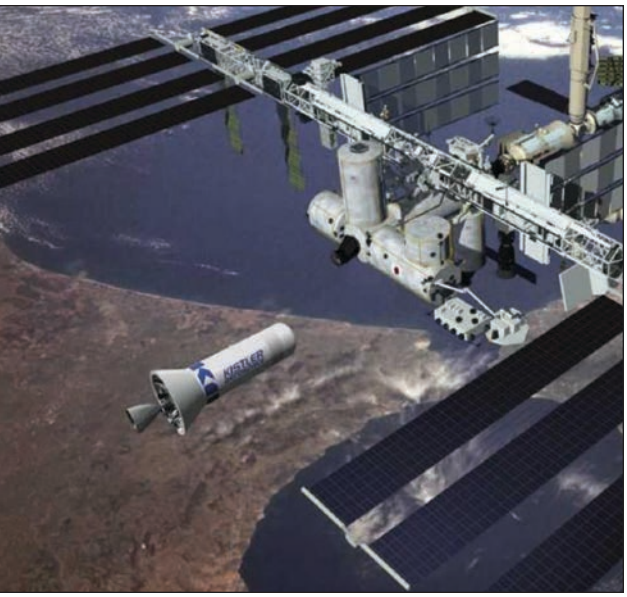
Also present were venture capitalist Alan Marty and JSC attorney Jonathan A. Arena. The due diligence sessions included negotiations on Space Act Agreements and desired funding levels, sometimes requiring days of back-and-forth discussions between the companies and NASA legal and procurement personnel.[140] Companies were also invited to address any weaknesses evaluators may have found, and the PEP subsequently adjusted the findings and color ratings for each competitor. As a result of this process, most of the companies were able to improve the ratings for their business, technical, and financial plans.[141]



Credit: SpaceX

SpaceX responded to NASA's COTS Announcement with a proposal that included a two-stage Falcon 9 launch vehicle (left) capable of delivering 78,000 pounds of thrust, and the capsule-shaped Dragon to carry crew and cargo to and from the ISS. After separation from the rocket, the Dragon would travel to the International Space Station where an ISS astronaut would use the Canadarm2 to grapple the spacecraft (right).

During the final phase of the selection process, on August 15 and 16, each finalist was allowed two speakers to explain the company's proposal to the Headquarters selection team—an added measure not typical of NASA procurements.[142] Of the six finalists, Horowitz and his team found SpaceX to be the clear leader for both the technical strengths of the company's Falcon rocket and Dragon spacecraft, as well as the company's solid finances and plan for capturing a share of the launch market.



Credit: KAS 1989-2002

Rocketplane Kistler proposed its K-1 launch vehicle for crew and cargo launch services to the ISS. (Top photo) The fully reusable system was designed to accommodate a wide range of missions and launch satellites to a geosynchronous orbit. Operating in two stages, the K-1 Launch Assist Platform (first stage) was designed to carry the Orbital Vehicle (second stage) to its trajectory in low-Earth orbit. For NASA's COTS program, the Orbital Vehicle could be configured to transport per mission about 2,900 pounds of cargo or up to five crew members (bottom photo).

For the second partner, Horowitz narrowed the selection down to two potential companies. Rocketplane Kistler exhibited an impressive technical plan for the reusable K-1 launch system, but had some weaknesses in its financial credentials. On the other hand, SpaceDev presented a stronger business case, but had a less credible technical plan for developing its Dream Chaser spacecraft. The Dream Chaser was based on NASA's HL-20 lifting body concept from the early 1990s, and would utilize an Atlas V launch vehicle to reach low-Earth orbit.[143]

Although "the executive council was evenly divided between these two finalists," NASA ultimately selected RpK as the second COTS partner. Horowitz noted in the Final Selection Statement that "SpaceDev's technically complex design with its associated adverse cost and schedule implications was a greater risk than RpK's financial uncertainty."[144]

The inclusion of financial milestones to mitigate RpK's known financing risk contributed to the Selection Authority's decision.[145] As Horowitz would explain later, "In order to be selected they had to be technically viable. That was the tipping point."[146] Furthermore, RpK proposed to provide services on an earlier timeline, and its requested contribution from NASA fit within the available COTS funding.[147]

On August 18, 2006, SpaceX and RpK signed the first funded Space Act Agreements of the COTS competition. The companies were awarded a total of $278 million and $207 million respectively (based on the amounts requested in each company's proposal) to be paid in increments upon completion of each of the negotiated milestones.[148] The milestones were placed at intervals of roughly one every quarter, allowing NASA to periodically track their progress, but without undue interference.[149]

Credit: C3PO team

Serving as the Selection Authority, Scott "Doc" Horowitz, NASA Associate Administrator of Exploration Systems Mission Directorate (ESMD), signed the Space Act Agreements, August 18, 2006, officially starting the NASA Commercial Orbital Transportation Services program partnerships with SpaceX and RpK. Sue Fenn, ESMD Executive Assistant, is also pictured.

Round 1 Protest

In late 2006, NASA received the first legal challenge to the Agency's use of funded Space Act Agreements. Exploration Partners LLC—one of the unsuccessful proposers from the COTS Round 1 competition—argued to the Government Accountability Office (GAO) that the company should have been awarded one of the COTS Space Act Agreements, on the grounds that it was "the only company that offered a fully funded end-to-end transportation system."[150]

On December 19, 2006, GAO denied the Exploration Partners protest. First, GAO found that the

protest was not submitted in a timely manner. Second, in what was described as a "landmark" case for the Agency, as a result of the protest, GAO determined that it did not have jurisdiction over the award of funded Space Act Agreements.[151] Past precedent had determined the GAO's lack of authority over cooperative agreements, and this case extended the same principle to other non-contract awards, including SAAs. GAO only monitors whether or not the Agency used the appropriate legal instrument; i.e., whether NASA was justified in its use of an SAA or should have used a traditional procurement.

The COTS legal team at JSC and NASA Headquarters credited their diligence during the formation of COTS for the successful defense of the Agency's funded Space Act Agreements. Even before the SAAs were awarded, the attorneys made sure to forge a consensus within NASA so that all the involved parties understood that these awards were not for goods or services being purchased for the direct benefit of the government, but rather to stimulate a public purpose.[152]

Attorney Karen M. Reilley explained how "not only did we need to come up with a process, educate ourselves and the rest of our own internal community, but document that. We made sure that we had a good record, literally on paper, of the decision-making process that we had gone through."[153] Arena added, "As lawyers, we wanted it to be defensible. We knew what we were doing was very unique, and so we were likely to get criticized."[154]

Round 2

In October 2007 NASA elected to terminate the SAA with RpK, citing the company's failure to meet its financial and subsequent technical milestones. Aware that they may need a contingency plan of action as RpK began to falter, the COTS team began brainstorming how to proceed forward with the program. Instead of allocating the funds to a runner-up from Round 1, C3PO decided that the best way to continue the program's goals was to hold another round of competition and selection. This advanced planning allowed C3PO to announce a new competition within a month of RpK's official termination.

NASA had paid a total of $32.1 million to RpK, which after an approximately five percent reduction for program operations left $170 million of unassigned COTS money for a new partner. The Round 2 Announcement issued on October 22, 2007, gave previous competitors the opportunity to submit updated or improved financial and technical information, while also allowing new competitors a chance to propose plans for the remaining funds.[155]

Lessons Learned

Due to the success of the COTS Round 1 selection, the team was able to use an almost "cookie cutter" approach for Round 2, retaining many of the same elements and people who had participated in the first selection.[156] The basic text and structure of the Announcement remained almost identical, but some modifications reflected lessons learned from the first competition. For example, each company was limited to submitting one proposal. Other changes refined the structure of the proposal, reduced the page count, and updated ISS interface requirements.[157]

The Round 2 Announcement asked for additional financial data in the proposal which previously was requested during due-diligence meetings. This enabled the business team to have all financial data earlier in the process for thorough evaluation.[158]

Similarly, the COTS team was able to further streamline the evaluation and due diligence process, while maintaining most of the elements that had worked well during the first round. Retaining most of the same PEP members and committee chairs contributed significantly to the efficiency of the Round 2 selection. One change was the consolidation of the COTS business and finance functions into one business committee. According to Xenofos, "We got a little bit smarter about how we did the evaluation process," though the process was still not disclosed to companies in detail.[159]

Selection

NASA received 13 proposals by the November 22, 2007, deadline that gave companies one month to prepare their Round 2 submissions. Some of the Round 2 participants had applied during Round 1, such as Andrews Space, Boeing, Orbital Sciences Corp., and SpaceX, and four of the companies had signed unfunded Space Act Agreements with NASA earlier that year to help them develop their technology without milestone payments. A few new competitors, such as TGV Rockets, Inc., also joined the race.

Credit: Orbital Sciences Corp.

For the COTS Round 2 selection, Orbital Sciences Corp. proposed its Taurus II launch system (left). Later renamed Antares, this was the first vehicle developed by the company to use a liquid first stage. Antares (top right) would be equipped with Aerojet AJ-26 engines and utilize on its second stage a solid rocket motor from ATK. To deliver cargo to the ISS, Thales Alenia Space in Italy would build Orbital pressurized and unpressurized cargo modules (bottom right).

Four proposals were eliminated due to deficiencies in their business plans. The SpaceX proposal was dismissed because it "was only to accelerate the crew transportation capability under its existing funded Space Act Agreement and did not provide an executable demonstration plan within the available NASA funding."[160] The remaining eight proposals were evaluated according to levels of confidence, using the same process as in Round 1.

Of these eight, five finalists were selected to proceed to the step of due diligence: Andrews Space, The Boeing Company, Orbital Sciences Corp., PlanetSpace, Inc., and SpaceHab, Inc. In February 2008, Selection Authority Douglas R. Cooke, who succeeded Horowitz as Associate Administrator for ESMD, ultimately selected Orbital Sciences Corp. as the winner of the COTS Round 2 competition. Cooke's decision between the two strongest contenders, Orbital Sciences Corp. and The Boeing Company, hinged on two deciding factors.

First, in Cooke's analysis, the most immediate ISS need was for cargo delivery and disposal, i.e., Capabilities A and B. Although cargo return for scientific research samples and crew (Capabilities C and D) were "desired," they were not as necessary at the time of the selection, particularly considering that other routes to crew transportation were available from the Russian Federal Space Agency (Roscosmos) and the Orion crew capsule being developed under the Constellation Program.[161] Boeing proposed all four

capabilities, with crew as an unfunded option, but Orbital's proposal of only capabilities A and B fit better within the needed portfolio of commercial transportation services.

Second, as Cooke stated in his Selection Statement, "A key discriminator in this decision is the business plan for each company."[162] NASA had learned from experience that a company's financial stability was just as important, if not more so, than its technical approach. Boeing and Orbital had the two strongest business cases of the finalists, but Boeing proposed to buy launch services from other companies, whereas Orbital was developing its own launch vehicle, the Taurus II (later renamed Antares). Launch costs would therefore be more directly under Orbital's control.

Furthermore, Orbital already had the internal funds necessary to complete to development; the company had no need to seek additional investors or income. Antonio L. Elias, Orbital Executive Vice President and Chief Technical Officer, described the moment when he explained the company's finances to COTS representatives during due diligence meetings: "It was as if this huge load had been lifted, a sigh of relief. All of a sudden the great black cloud on top of the COTS program had been released."[163]

Cooke also found that in the areas of science missions and small satellite launches the Taurus II would meet a real market need for a medium launch vehicle capability, which he said met the "objective of COTS to stimulate a broad space transportation market for multiple customers."[164]

NASA signed the funded Space Act Agreement with Orbital Sciences Corp. on February 19, 2008, incorporating the lessons learned from RpK's termination. In the words of Project Executive Bruce Manners: "NASA does a really good job at understanding what technical risks are. But since we had gotten our hands burnt on what was always RpK's biggest risk on the business side, which was outside of our realm," in Round 2 "we picked somebody that was a fairly low business risk, who already had the money in-house and the ability to put this together."[165]

Round 2 Protest

In January 2008, GAO decided the second protest regarding the COTS program. After NASA terminated its Space Act Agreement with Rocketplane Kistler in October 2007, the company protested the subsequent COTS Round 2 Announcement to issue RpK's remaining funds to another commercial partner. RpK claimed "that the principal purpose of the announcement [was] to obtain research and development services for the direct benefit of NASA," and therefore should have been issued under a procurement contract instead of a Space Act Agreement.[166]

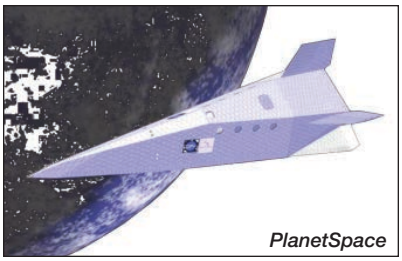
This protest was also denied, on the grounds that "the record supports the agency's arguments that the principal purpose of the announcement is to encourage, support and stimulate the development of a commercial market for space transportation"—not to obtain a good or service for the direct benefit of the government, which would in fact require a procurement.[167]

Unfunded Space Act Agreements

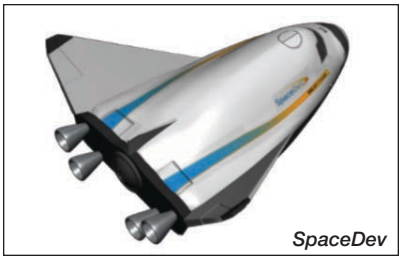
An important element of the COTS program was NASA's decision to also work on an unfunded basis with some of the non-selected companies. On January 31, 2007, NASA signed Commercial Space Transportation Capabilities Agreements, or unfunded Space Act Agreements, with PlanetSpace and t/Space, two of the unsuccessful proposers from the Round 1 COTS competition. These non-reimbursable SAAs were followed a few months later with similar agreements signed on June 15, 2007, with three of the other Round 1 offerors: Constellation Services International, SpaceDev, and SpaceHab.[168]

These agreements allowed the partners access to NASA technical expertise without the payments of funded SAAs. The unfunded SAAs did include milestones, but C3PO observed their completion as opposed to conducting a formal evaluation. Sometimes the process was as simple as receiving a letter from an unfunded partner indicating they had achieved the required milestone criteria.

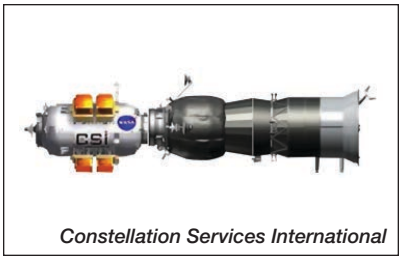
Being able to continue these companies' relationship with NASA after the selection decision was important to Lindenmoyer. "He was insistent," recalled NASA attorney Sumara Thompson-King, because the purpose of COTS was "to stimulate industry, so having those unfunded agreements would keep those folks in the game."[169] They



PlanetSpace

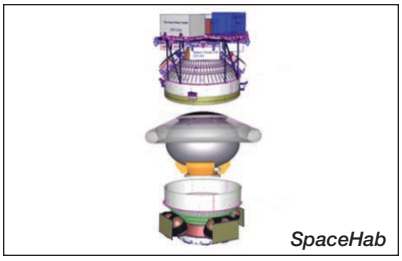


SpaceDev



Constellation Services International

t/Space



SpaceHab

NASA entered into unfunded Space Act Agreements with companies not selected in the COTS Round 1 selection process, allowing these partners access to NASA technical expertise to assist companies in further development of their vehicles. Above are illustrations of the concepts proposed by the five partners.

would have the chance to continue the development of their vehicles for future NASA competitions, and NASA was able to show the Agency's support for commercial space transportation initiatives.[170]

Having established the legal framework for the COTS funded SAAs, the team of NASA attorneys also made these unfunded agreements possible. Through "robust" conversations and policy study, the lawyers determined that NASA would be able to pursue unfunded cooperation with these industry partners to help provide technical advice, but without going so far as to use the agreement as a NASA endorsement.[171]

Although no set rule existed for how many unfunded agreements were possible, the extent of help was limited to available NASA personnel time. Each of the unfunded partners was assigned to one of NASA's two project executives, who were available to answer telephone calls and arrange for additional technical assistance if necessary.[172]

All of the companies with unfunded SAAs, except Constellation Services International, submitted proposals for the COTS Round 2 competition, with PlanetSpace and SpaceHab making it to the final round. Both PlanetSpace and SpaceHab were highly rated for their technical approaches for Capabilities A through C, but the companies fell short on their respective business plans.[173]

Following the Round 2 COTS award, three of the unfunded COTS participants elected to unilaterally terminate the agreements with NASA. On May 29, 2008, SpaceHab gave 30-day notice of its termination, stating, "We are unable to continue to meet our milestones using only internal funding."[174] Constellation Services International followed on July 15, 2008, reporting that its ISS commercial cargo resupply service project was being put into "indefinite hibernation."[175] That October, t/Space also unilaterally terminated the company's unfunded SAA with NASA.[176]

SpaceDev was acquired by the Sierra Nevada Corp. in October 2008, and the company continued development of the Dream Chaser vehicle as part of NASA's subsequent Commercial Crew Development (CCDev) Program. PlanetSpace competed for the ISS Commercial Resupply Services contract awarded in December 2008, but was outdone by funded COTS participants SpaceX and Orbital.

Program

Funding

Organization

Operations

Chapter 4

NASA's Commercial Crew & Cargo Program Office (C3PO) contributed to the development of commercial space transportation services by offering a new form of partnership between the space agency and private industry. The success of this effort depended on the synthesis of limited government funding, an innovative operating philosophy, and the people who put these elements together.

C3PO focused on administering NASA's obligations under the Commercial Orbital Transportation Services (COTS) Space Act Agreements. This included verifying that partners met their predefined milestones, processing milestone payments, and providing technical expertise and support to the partners when needed.

Funding

The COTS program aimed to maximize the use of government funds in order to stimulate the U.S. commercial space transportation sector. Of the $500 million originally allocated in 2006, C3PO designated only 3 percent for program management, leaving 97 percent, or about $485 million, to give directly to the commercial partners. In its five-year operating plan set forth in August 2006, C3PO planned the distribution of its budget in such a way that the majority of funds would be available to the commercial partners in the middle of their development programs (see table below).[177]

In the first round of COTS competition in 2006, $278 million was awarded to the Space Exploration Technologies Corp. (SpaceX) and $206 million was awarded to Rocketplane Kistler (RpK).[178]

The C3PO budget request for fiscal year 2008 (October 2007 through September 2008) had been submitted to NASA Headquarters in the summer of 2006—before C3PO was officially incorporated and before the Round 1 competition had been announced—and asked for a $236 million appropriation. By the time the fiscal year 2008 budget was signed into law in December 2007, the plan and circumstances of C3PO operations had changed. Most significantly, the SAA with RpK had been terminated two months previously.

Congress appropriated only about $160 million to C3PO, a $76 million reduction, and the bill specified that COTS could not move forward with the selection of a second commercial partner until the Government Accountability Office (GAO) protest regarding the COTS Round 2 Announcement had been decided. According to COTS Resource Analyst Lisa P. Price, a Congressional staffer asked the program if it could accept a budget reduction in fiscal year 2008 in exchange for greater appropriations in later years. Price and her colleagues were then able to develop a phasing plan that allowed for the continuation of the SpaceX SAA and the selection of a new partner under the program's revised budget profile.[179]

COTS Project	FY06	FY07	FY08	FY09	FY10	**Total**
Funding ($M)	52	91	193	130	34	**500**

Originally planned COTS funding.

In January 2008 the GAO denied the Round 2 protest, freeing NASA to select Orbital Sciences Corp. as its new partner in February 2008. Orbital was awarded a funded Space Act Agreement (SAA) for the remaining $170 million of available COTS funding. At this point C3PO increased the percentage of the budget withheld for program management from 3 percent to about 5 percent to accommodate the additional development time needed for NASA's new partner. C3PO Manager Lindenmoyer reported that a traditionally run NASA Program may dedicate 10 to 15 percent of its budget to overhead, so even at the increased 5 percent level, COTS still represented a significant cost savings when compared to traditional NASA programs with markedly higher management costs, and budgets in the range of tens of billions of dollars.[180]

In addition to C3PO's novel use of funded Space Act Agreements that allowed partners to receive payment only after the completion of predefined milestones, the program also applied innovation to the process for partner milestone payments. Under procurement contracts, payment could take up to 15 or even 30 days, but in her role as the COTS Resource Analyst, Price was able to coordinate with her colleagues to establish a process that allowed payments to be deposited in the company's bank account within only 3 days of milestone approval. Price described her goal as an effort "to get that money to the partners as quickly as we could so that they could continue to work without interrupting their efficiency."[181]

Augmentation

C3PO continued to operate with the understanding that it would have only the original $500 million funding allocation to complete the development of both partners' commercial space transportation systems. However, around 2009 NASA and Congressional leaders began to assess the need to maintain ISS operations after the impending retirement of the Space Shuttle (originally planned for 2010).

William H. "Bill" Gerstenmaier, NASA Associate Administrator for the Space Operations Mission Directorate, explained how additional funds were needed to provide "mission assurance" for the commercial resupply capabilities that were becoming increasingly critical to the Agency's mission.[182] Gerstenmaier reflected that, "the focus had changed a little bit. Development of this new industry was going to be critical to us in the future. It was time to invest a little bit more money to keep that moving forward."[183]

Meanwhile, advocates of NASA's new way of doing business had been working to promote COTS to important policy influencers in Washington, DC, particularly the Review of United States Human Spaceflight Plans Committee. The White House Office of Science and Technology Policy commissioned the committee in May 2009 to review the nation's progress and plans for space exploration. More often referred to as the Augustine Commission for the panel's chair, Norman R. Augustine, this group of spaceflight experts included former NASA astronauts and representatives from private aerospace corporations.

Bretton Alexander, former President of the Commercial Spaceflight Federation, later reflected that "by putting someone like Norm Augustine

In May 2009 the White House Office of Science and Technology Policy commissioned a panel to review the nation's progress and plans for space exploration. Referred to as the Augustine Commission, this group of spaceflight experts recommended NASA's commercial cargo initiative receive more funding to "incentivize" the COTS cargo demonstrations. C3PO ultimately received a $300 million augmentation as a result of this assessment.

Credit: NASA/Paul E. Alers

Norm Augustine (right) chaired the 2009 Presidential Commission, Review of U.S. Human Spaceflight Plans Committee. Serving as one of the panel members was Sally Ride, the first American woman in space. Ride (left) presented the Commission's analysis that included the recommendation of a one-time funding addition to the COTS cargo budget.

at the top, I would have thought you were guaranteeing it to never say anything good about [NASA's] commercial [initiatives], because he was not known for that."[184]

However, to the surprise of Alexander as well as C3PO, the committee advised that more funding be added to NASA's commercial cargo initiative. Members of the COTS team at JSC reported first hearing of this recommendation to add funds to the C3PO budget while watching CSPAN coverage of an Augustine Commission hearing in Washington, DC on August 12, 2009. Committee member Dr. Sally K. Ride, the first American woman in space, presented the Commission's "Scenario Affordability Analysis," and announced:

"We elected to add an additional $200 million—this is a one-time add—to the COTS cargo baseline in FY '11 … to incentivize the current COTS cargo demonstrations. We've all come to realize how important the COTS cargo is to the future of ISS, and we want to make sure that there's incentive for them to perform as we all hope they will."[185]

The eventual Augustine Report released to the public on October 22, 2009, included the statement that, "NASA's planned transition of much of the International Space Station (ISS) cargo resupply to the commercial sector is a positive development. Financial incentives should be added to those suppliers to meet their schedule milestones."[186]

The White House accepted the Augustine Commission's recommendation for augmented COTS funding. NASA's FY 2011 budget request, submitted in February 2010, asked Congress for an additional $312 million for commercial cargo development, a 62 percent increase over the $500 million budget that C3PO had been allocated in 2006.[187]

Furthermore, as a result of the Augustine Commission's finding that the Constellation Program was too far behind schedule and too over budget to meet its goals, in February 2010 President Obama announced the program's cancellation. In addition to the retirement of the Space Shuttle, Marc G. Timm from NASA Headquarters called this decision "a big turning point, where the partners became the primary systems for transporting cargo to and from Station."[188]

The NASA Authorization Act of 2010, passed on October 11 of that year, explicitly approved NASA's plan to augment C3PO funding. It stated that, "$300,000,000 shall be for Commercial Cargo," and that "the Administrator may apply funds towards the reduction of risk to the timely start of these [commercial] services."[189]

This $300 million augmentation (slightly less than the $312 million NASA requested since $12 million was needed to complete the original $500 million program) helped ensure that commercial cargo resupply services to the International Space Station would be available after the retirement of the Space Shuttle in July 2011. For more on how these augmentation funds were applied, see Chapter 5: Commercial Partners and Chapter 6: Collaboration.

Organization

C3PO operated with a very small full-time staff to implement its partnerships with industry. At most, 14 NASA civil servants were employed in C3PO, in comparison to traditional programs that employed hundreds of government employees to monitor technical development.

The small percentage of the C3PO budget designated for program management was judiciously applied to cover the salaries and travel of program office personnel; support from JSC safety, budget, and procurement offices; as well as funding for "as needed" expertise. As Price stated simply: "The size of the workforce drives the cost."[190]

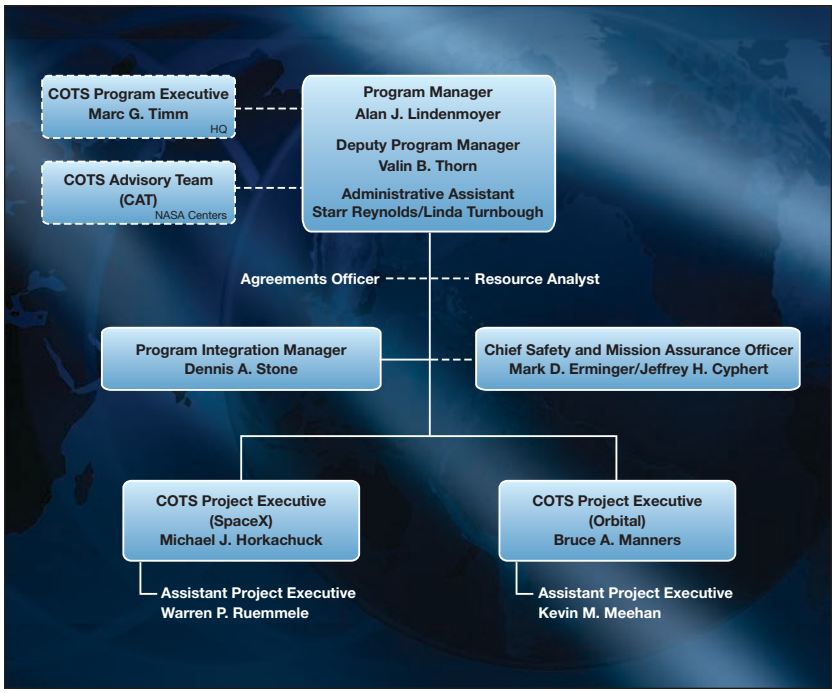
The program maintained lean operations, relying heavily on its project executives and assistants, and drew on engineers and technical experts from across the Agency to create an "on-call" team known as the COTS Advisory Team (CAT). A designated Safety and Mission Assurance Officer was involved throughout the program. Marc G. Timm, the Program Executive at NASA Headquarters, with the aid of assistant Andrea M. Riley, served as the liaison between the program office in Houston and senior NASA officials in Washington, DC.[191]

Project Executives

Not only did C3PO work towards the most effective use of limited government funds, the program emphasized limited NASA oversight to allow the commercial partners to pursue innovation. The project executives and their deputies served as the essential conduits for communicating NASA information to commercial partners and vice versa. Both worked to establish a true partnership with their respective industry partners, lending NASA expertise and providing guidance on spacecraft development rather than relentlessly monitoring the implementation of specific, NASA-imposed requirements.

The position of the COTS project executives was somewhat analogous to the job a project manager might do in a more traditional Federal Acquisition Regulation-based contract, but there were important differences. According to Bruce A. Manners, the COTS Project Executive for RpK and Orbital, the project executive served more as a facilitator without dictating, driving, or owning the design or the program. He added that with COTS, NASA was trying to do something "broader" and not just expecting the companies to "answer our requirements." Manners also said that at times he had "to reel" himself in and not give the companies the direction that they sometimes wanted in order to allow them to make a better business decision.[192]

Michael J. "Mike" Horkachuck, NASA Project Executive for SpaceX, shared, "Sometimes I'd just ask questions in a framework to make them think. Not necessarily looking for an answer immediately … but it's a seed."[193] Because the project executives and their respective assistants closely followed the philosophy of guiding without forcing solutions, they were able to share technical expertise and lessons learned in a genuine partnership relationship. "It's much more managing through influence than it is managing through force of position," said Manners.[194]



Instead of the large organization typical of major NASA programs, the space agency used a small program office of about 10 civil servants to manage COTS.

NASA Deputy Administrator Lori B. Garver observed that NASA's relationship with the commercial partners was akin to "grandfathers taking their grandsons fishing," using a "gentle touch" to guide their protégés in the right direction.[195] Furthermore, due to the nature of funded Space Act Agreements, there was no haggling over the cost of changes that is experienced with a typical contract, allowing for a more harmonious relationship.

For both of the project executives, this new role also meant the acquisition of new skills. Manners and Horkachuck increased their business and financial proficiency through the COTS team's collaboration with venture capitalist Alan Marty, knowledge which would become increasingly necessary as RpK began to slip on its financial milestones. Horkachuck also undertook additional training in how to handle the increased media attention resulting from the SpaceX COTS demonstration missions.[196]

Bruce Manners

After receiving a B.S. degree in Electrical Engineering from Ohio Northern University in 1988, Bruce Manners spent the first years of his NASA career at the Glenn Research Center (GRC) in Cleveland, Ohio, working on the ISS electrical power system. Manners eventually progressed to the position of Supervisory Engineer of the Power Systems Analysis Branch, where he came to know both future C3PO Manager Alan J. Lindenmoyer and Deputy Program Manager Valin B. Thorn through the ISS office. While serving as a liaison for GRC at the Johnson Space Center (JSC), Thorn invited Manners to participate in the Participant Evaluation Panel as a member of the technical committee.

Shortly after helping evaluate the COTS proposals in early 2006, Manners permanently relocated to JSC and began work on power and propulsion for the Constellation Program, where Manners reported he was able to draw on his experience and professional ties to form a partnership between engineers at GRC and JSC. In the fall of 2006, he was asked to utilize these skills as the NASA project executive for RpK. After NASA terminated its Space Act Agreement with RpK in October 2007, Manners participated in the Round 2 COTS selection as a voting member of the Participant Evaluation Panel, which awarded the remaining funds from RpK to another competitor. He began his work as the NASA project executive for Orbital Sciences Corp. in February 2008.[197]

Mike Horkachuck

Mike Horkachuck worked with SpaceX as the NASA project executive from August 2006 through the completion of the company's Space Act Agreement in 2012. Horkachuck graduated from the University of Southern California in 1983 with a degree in Mechanical Engineering, and began his NASA career at the Ames Research Center, where his work on the 1.8-meter centrifuge for ISS research involved extensive coordination with the Space Shuttle and Station programs. In 1996 Horkachuck moved to JSC, eventually being promoted to Manager of ISS Payload Hardware Engineering Integration, managing the team that integrated hundreds of science payloads with ISS and the Shuttle.

As part of his ISS integration work, Horkachuck had previously studied options for how to return experiment samples more frequently to Earth than was possible with the Space Shuttle, and helped include this important need into the high-level ISS goals being developed for the nascent COTS program at the end of 2005. After some months as Chief of Development Testing and Verification Strategies for the Constellation Program, in September 2006 Horkachuck joined the COTS team full-time as the NASA Project Executive for SpaceX.[198]

In addition to his intimate knowledge of ISS integration, Horkachuck's previous positions also involved partnership-type collaborations with the European Space Agency, experience that could be applied to his new role. After years of working within the confines of traditional NASA procedures, Horkachuck was ready to a support a more efficient way of doing business. He found SpaceX an appealing choice for a partner. "I liked their innovative style, and it just seemed like they were a more natural fit with my management style," he said.[199]

Assistant Project Executives

Throughout the COTS program, Horkachuck and Manners relied on the support of their assistant project executives. Assistant Project Executive for SpaceX Warren P. Ruemmele brought his experience in mechanical engineering and as a Contracting Officer Technical Representative and Technical Management Representative to the collaboration. Horkachuck described

Credit: C3PO team

SpaceX displayed a Dragon spacecraft during the 2011 Innovation Day event at the Johnson Space Center. Standing by the exhibit are C3PO team members: (front, left to right) Bruce Manners, Stan Whalen, Mark Erminger, Joyce Repa, Starr Reynolds, Alan Lindenmoyer; (back) Elijah Williams, Warren Ruemmele, Mike Horkachuck, Tom Clemandot, Derek Jones, Valin Thorn, John Bretschneider.

multiple occasions when he relied on Ruemmele's aid, for example in assembling the COTS Advisory Team and searching for NASA resources that could help SpaceX meet its milestones.[200] Assistant Project Executive Kevin M. Meehan similarly supported Bruce Manners in NASA's engagement with RpK and Orbital.

The COTS project executives and their respective assistants were the key links in the public-private partnership between NASA and commercial space transportation companies. By respecting the commercial partners' unique business models and providing insight rather than oversight, the NASA project executives were able to forge bonds that ultimately resulted in the successful development of U.S.-based commercial space transportation capabilities.

Chief Safety and Mission Assurance Officer

Throughout the program, C3PO included the position of a designated Chief Safety and Mission Assurance Officer. As a demonstration of the priority given to safety and mission assurance, the safety officer was given a voting role as member of the Participant Evaluation Panel in both COTS competitions.

The safety officer collaborated with the COTS team and the commercial partners to assess various areas of risk, and periodically conducted essential established safety reviews. He participated in major technical investigations as well as every major partner quarterly and milestone review. Additionally, the safety officer played an active role in C3PO program-level boards and meetings.

The NASA safety officer's job included developing mishap preparedness and contingency plans for each major integrated vehicle launch pad test and flight, detailing what steps would be taken in the event of a mishap or incident, and who would be responsible for leading an accident investigation. Prior to each demonstration mission, a mishap simulation was conducted that included all responsible parties in the event of an incident. These included representatives from C3PO, the Federal Aviation Administration, and the National Transportation Safety Board, as well as the NASA Headquarters Chief of Safety and Mission Assurance and the Associate Administrator for the Exploration Systems Mission Directorate.

Mark D. Erminger served as the safety officer from September 2006 until his

retirement in September 2012, when Jeffrey H. Cyphert took over the role.

Throughout the program, the C3PO Chief of Safety and Mission Assurance maintained communication with the JSC Safety and Mission Assurance Manager and the Office of Safety and Mission Assurance at NASA Headquarters. Due to the hands-off structure of COTS, however, the JSC safety officer was not always able to share as much in-depth technical information as Headquarters officials were accustomed to having. Cyphert reported this was part of the learning curve in working with commercial providers as opposed to traditional NASA contractors.[201]

Mark Erminger

Mark Erminger received a Bachelor of Science degree from the U.S. Air Force Academy in 1978, and an M.B.A. from the University of Missouri in 1980. In 1981 Erminger began his NASA career at the Johnson Space Center, where he worked in the Crew Training Division. In this position he trained astronauts and flight controllers on Space Shuttle operations and systems. In 1987, Erminger became a flight controller himself.

With more than 10 years in Shuttle operations, Erminger was acutely aware of the critical importance of safety issues in low-Earth orbit. In 1992 Erminger moved to the office of Space Shuttle Safety, Reliability, and Quality Assurance as its Manager. Among his other duties, in this position Erminger coordinated the safety reviews of flight readiness for Space Shuttle and Space Station missions between three field centers and NASA Headquarters.

From 2003 to 2005, Erminger used this experience as Executive Director of the Aerospace Safety Advisory Panel (ASAP) at NASA Headquarters, after which he returned to JSC as the Chief Safety and Mission Assurance Officer for the COTS program.[202]

COTS Advisory Team

Under COTS, the commercial partners, not NASA, established their own requirements and were responsible for the design, development, and testing of their spacecraft. However, C3PO recognized at the beginning of COTS that subject matter experts would be needed to advise the partners in particular areas of technical expertise. Maintaining a full-time contingent of engineers was inconsistent with the COTS approach of lean operations. Instead, the COTS team used periodic targeted support when specific needs arose, especially for the major technical reviews. This group became known as the COTS Advisory Team, or CAT. Members were often referred to as CATs.

The CAT served two main functions: providing partners with NASA's technical expertise and advising C3PO on whether partner milestones were completed satisfactorily. The teams were similar to the support teams that Horkachuck had set up for the Constellation Program, as well as Boeing vehicle team support hours that were used by the ISS Payloads Office to work technical issues. A group of technical experts were identified for each discipline and an approximate budget of hours was allocated to allow for that support when needed.

This NASA engineering expertise was vital to COTS. Employing "as needed" experts helped create a more efficient process for the development of the commercial partners' vehicles by lowering NASA overhead and reducing costs for dedicated COTS personnel. Indirectly, this arrangement also saved the commercial partners money, since development delays did not result in an idle team of engineers waiting for work. When challenges arose, they were able to utilize CAT expertise without hiring their own full-time support staff.

To identify CAT members, C3PO staff reached out to engineers they had worked with previously, many of whom saw the COTS philosophy as "interesting and challenging."[203] Availability posed something of an issue at the beginning of the COTS program, as many engineers were occupied with work on the Shuttle, ISS, and Constellation Programs. Project executives sometimes encountered difficulty finding consistent support for reviews. To remedy this, a dedicated point of contact was later established at each NASA center to help access personnel.[204] All NASA centers provided CAT support, including

As part of COTS development and demonstration programs, partners met technical milestones that included major engineering reviews and engine tests. NASA team members traveled to the SpaceX facility in McGregor, Texas, which has a number of testing stands, including the tripod shown below that is used to test the nine Merlin engines on the Falcon rocket.

Credit: C3PO team

engineers from the Marshall Space Flight Center in Huntsville, Alabama, with its rich history of rocketry and propulsion.

CAT expertise grew to cover more than 30 subsystem disciplines, and numbered 100-plus individuals. Main CATs disciplines in addition to propulsion included avionics; electrical power; structures; parachutes; thermal control; thermal protection; communication and tracking; guidance, navigation, and control; and pyrotechnics. David W. Thompson, CEO and President of Orbital, remarked that, "We had roughly half of the field center network within the Agency at one time or another, providing know-how or surplus equipment to our work, which made a big difference."[205]

When working through crack and corrosion issues with its AJ-26 rocket engines, Orbital Sciences Corp. engineer Kurt Eberly stated that "it was essential to bring all that history that [Marshall engineers] have working with cracked metals." He described how "they're able to really step in and quickly analyze the materials" in order to "help us through the process of developing the weld repair process and the inspection process that assures us that the engines are going to be flightworthy."[206] Said SpaceX Mission Manager Peter Capozzoli, "NASA was very willing and very open to lend their expertise wherever we asked, and often offered up places where they thought they could help."[207]

CAT members were assigned to support both commercial partners equally; no CAT members supported one partner exclusively, allowing NASA to be somewhat consistent in the advice provided. Because the majority of company data was considered proprietary, each CAT member signed a non-disclosure agreement (or inherently protect proprietary data as a civil servant), acknowledging the importance of handling partner data appropriately and keeping data separate from the other partners.

Credit: NASA/Stennis Space Center

NASA Stennis Space Center in Mississippi conducted test firings on the liquid-fueled Aerojet AJ-26 engines used to power the first stage of the Orbital Sciences Corp. launch vehicle. The first in a series of three firings, this test (pictured above) on November 11, 2010, was held to verify start and shutdown sequences on the engines, along with test stand operations and ground-test engine controls.

Although most CAT members were NASA civil servants, some contractors also contributed, many of whom were former NASA civil servant "grey beards" who could draw on their wealth of experience from the Shuttle and even Apollo programs. This expertise allowed these engineers to transmit key lessons learned to the commercial partners, relaying what had and had not worked well historically at NASA.

The project executives reported having to "coach" the CAT members early in the program, reminding them that COTS worked differently than previous NASA programs they had supported.[208] Horkachuck and Manners specifically explained that under the Space Act Agreements, CATs would be asked to offer their best technical advice, rather than certifying that a design adhered verbatim to NASA requirements and standards. They reviewed commercial partner data and documented potential concerns, sometimes working with the commercial partners to provide guidance and help with specific design challenges. However, they would not solve the commercial partners' issues or dictate design solutions.[209]

Commercial partners took the time to explain their design approach and company philosophy to CAT members, and the project executives clarified that due to this partnership-type relationship, the commercial partners had the option of not following CAT inputs, except those related to safety. In practice, very rarely were CAT recommendations not followed, and then only with a viable alternative approach.

A few early CAT members had difficulty accepting the COTS approach and were not invited to future technical reviews. However, the many who provided support throughout the program provided an element of continuity, as the commercial partners became comfortable with and trusted the advice of individual CAT members.

After the successful test flight of the Antares rocket, Orbital Senior Vice President of Antares Michael R. "Mike" Pinkston noted, "I heard nothing but rave reviews of the independent verification that was done on our guidance and control system that NASA had provided. It really bolstered our confidence going in, and I think the results bore out just how critical that help was to us, in terms of getting it right the first time."[210]

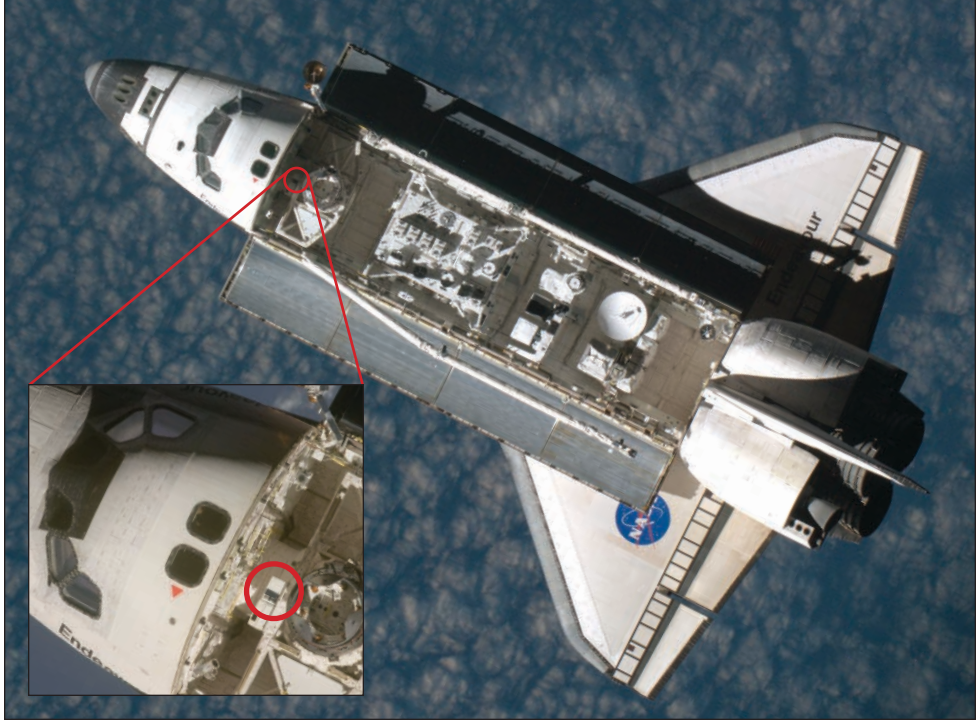
Program Integration Manager

While the project executives and their deputies focused on working with the partners, the C3PO Program Integration Manager, Dennis A. Stone, supported program operations that transcended individual partnerships. The program integration function covered a spectrum of activities including quality system compliance, external relations, website management, unfunded partner SAA negotiations, planning, and support contractor oversight.

Contractor Support

C3PO identified the need for a small amount of technical support, especially with the surge of activity predicted during the major milestone reviews. For the majority of the program, two to three full-time Booz Allen Hamilton support contractor engineers worked with the COTS team through the Advanced Planning Assessment Contract.

They designed processes that enabled C3PO to have insight into the progress of the commercial partners' space transportation systems. Main efforts focused on evaluating partner products and events associated with the SAA milestones. For example, the support contractor recommended using NASA Support Plans to provide the necessary timeline and documentation for each design review. These documents outlined the purpose of the review and detailed the roles and responsibilities for those involved.



A proximity sensor named DragonEye, developed by SpaceX, underwent flight system trials on the Space Shuttle Endeavour during the STS-127 mission in July 2009. This Laser Imaging Detection and Ranging (LIDAR) sensor system provides three-dimensional images based on the amount of time it takes for a single laser pulse from the sensor to reach a target and bounce back. The successful demonstration provided range and bearing information needed to guide the Dragon spacecraft during future ISS resupply deliveries.

As an example of its other contributions, Booz Allen recommended inputs to the SpaceX DragonEye Detailed Test Objective (DTO) I & II Project Requirements and Verification Document. The DTOs tested the relative navigation solution for maneuvering a cargo vehicle into position to be grappled by the ISS robotic arm and berthed to the Station. Since ISS integration constituted a major component of the COTS program, Booz Allen also evaluated ISS change requests for impacts to C3PO and the commercial partners.

Additionally, Booz Allen supported C3PO efforts to communicate activities to NASA Headquarters and the public, provided content recommendations to baseline performance review charts, budget reports, facility usage charts, etc., which went to the Center or NASA Headquarters. Also recommended were updates to ensure the C3PO website content was current.

ARES Corp. provided detailed schedule analysis and predictions of most likely launch dates. This was important to help NASA plan realistic support for the program, and proved useful in independent reviews of the program and for answering questions from officials at NASA Headquarters. ARES support was most notable when the first significant slips in milestones needed to be evaluated and recommendations made to NASA Headquarters on whether or not to continue the program.

Operations

Over its eight-year history, the Commercial Crew & Cargo Program Office instituted a new way of doing business with the private sector. In addition to the use of milestone-based funded Space Act Agreements and a focus on commercial viability, the COTS program pursued a unique approach in other aspects of its operations. The use of a small, "skunk works"-type team facilitated communications. The process of milestone assessment allowed NASA to verify completion of partner progress (necessary for the companies to receive payment) without undue oversight and interference.

Communications

C3PO aimed to maintain open lines of communication with COTS team members at JSC and NASA Headquarters (including legal and procurement), the general NASA community, NASA's current and potential industry partners, and the public. C3PO made a concerted effort, especially in the early days of COTS, to share the program's approach with the aerospace community. The team understood that the COTS philosophy was different from how industry had previously worked with the government, and would require a proactive effort to achieve widespread understanding of how NASA planned to foster the commercial space transportation industry.

The C3PO Program Integration Manager worked on developing the COTS ecosystem, those sectors on which COTS partners depended, such as investors, regulators, insurers, and non-government markets. This typically involved communicating with these sectors about COTS and NASA's plan to buy cargo services to ISS. Dennis Stone gave special attention to developing the market for microgravity services, which could open new demand for COTS partner vehicles as free fliers.

COTS team members also spoke at various aerospace forums, including the annual American Institute of Aeronautics and Astronautics (AIAA) Space Conference, as well as commercial space events such as the Space Frontier Foundation's annual NewSpace conference, and the annual Federal Aviation Administration (FAA) Commercial Space Transportation conference.

Although C3PO was small, it had reporting obligations to both the NASA Johnson Space Center and NASA Headquarters. Scheduled quarterly meetings allowed Lindenmoyer, the project executives, NASA Headquarters, and ISS representatives to meet with commercial partner executives and gain insight into the companies' progress. The results were summarized in quarterly reviews by C3PO with ESMD management.

COTS Program Executive Marc G. Timm at NASA Headquarters served as the program's conduit to other federal entities. These included Congressional offices, the Office of Management and Budget, and the White House. Said Timm, "The program wasn't set up to have a large contingent of folks to do that interfacing, so we purposely put together the processes that would allow us to accomplish this with a very small number of people."[211] He added he talked often with Lindenmoyer and worked closely with public affairs, legal, and legislative and intergovernmental affairs offices at NASA Headquarters.

Credit: NASA/Bill Stafford

NASA's Johnson Space Center in Houston hosted a media briefing in April 2012 to preview the SpaceX demonstration mission to the International Space Station. Pictured are (left to right), briefing moderator Josh Byerly; William Gerstenmaier, NASA Associate Administrator for Human Exploration and Operations; Mike Suffredini, Manager, International Space Station Program; Alan Lindenmoyer, Manager, Commercial Crew & Cargo Program; and Elon Musk, SpaceX Chief Executive Officer and Chief Designer.

Proprietary Data

A critical component of the COTS team's communication plan was to ensure they did not share the proprietary technical information that belonged to the commercial partners.

Although a traditional NASA contract may have some company data which the space agency must protect, in COTS nearly all the commercial partners' data was considered proprietary. The SAAs strictly precluded NASA from sharing partner data, even with NASA personnel, unless they were directly involved in reviewing partner milestones. C3PO's rigorous approach to protecting the companies' data included requiring all personnel who worked on the project, from NASA civil servants to contractors, to sign a non-disclosure agreement and maintain proprietary data in restricted online libraries.

Credit: SpaceX/Roger Gilbertson

As one of its COTS milestones, SpaceX conducted a series of high-altitude drop tests in August 2010 to validate parachute deployment systems and recovery operations. An Erikson S-64F Air-Crane helicopter dropped a test article of the Dragon spacecraft from a height of 14,000 feet, roughly 9 miles off the coast of Morro Bay, California.

Under traditional NASA contracts, the government typically owns the data and can use it for other programs. Everyone working on the COTS program understood they were allowed to use the partner data only for COTS support. In one case, CAT members at the Marshall Space Flight Center supporting Orbital's Antares rocket engines were evaluating use of the same Aerojet engines on another project. Bruce Manners, the NASA Project Executive for Orbital, described how C3PO had to be "rigid and specific" to ensure that the data and knowledge acquired under COTS was not applied to other efforts.[212]

Milestone Assessment

The COTS Space Act Agreements outlined a series of technical and financial milestones to be completed as part of the commercial partners' development and demonstration programs. Technical milestones typically consisted of major engineering reviews, engine tests, hardware delivery, and demonstration launches. After the COTS budget was augmented in fiscal year 2011, some extra technical milestones for SpaceX and Orbital were added to the SAAs, mainly for additional hardware and engine tests to reduce risk and enhance safety.

The language of the SAAs was intentionally written in broad terms with respect to milestone reviews. C3PO anticipated that the commercial partners' development programs would evolve, and with the aggressive COTS development schedules, the details of milestone verification were settled closer to the actual event. Some criteria, such as engine firings, were fairly easy to monitor and verify. Other criteria required a degree of discussion and negotiation between the COTS team and their industry partners.

The major technical reviews—System Requirements, Preliminary Design, Critical Design, and Demonstration Readiness—required the most NASA and COTS Advisory Team support, being the most complex of the various SAA milestones. The criteria for these reviews were tailored after the NASA Procedural Requirements document NPR-7123, NASA's standard for Systems Engineering Processes. The partners and the project executives agreed on the details and logistics of the engineering reviews, and the overall process evolved as COTS progressed.

While no two engineering reviews followed exactly the same steps from start to finish, all utilized a similar process. After C3PO determined the amount of support needed for a particular review, COTS Advisory Team members were recruited.

Early in the COTS program, ISS support was fairly limited, but became more intense as commercial partners approached the engineering milestones to prepare for their ISS demonstration missions. The ISS Transportation Integration Office coordinated the ISS support from its office and worked with C3PO throughout those reviews.

The partners organized documents into relevant subsystems and created suggested reading lists for the CAT subsystem teams due to the large amounts of documents and overlapping subsystems. An easy-to-use Review Item Discrepancy (RID)

form, once completed by the teams, was merged into one spreadsheet for efficient sort, review, and prioritization.

Typically reviewers had two to three weeks to submit RIDs. Then the support contractor facilitated a RID screening session, filtering on occasion up to 600 items. The screening sessions, sometimes two days or longer, would filter out RIDs that were out of scope for the COTS program, clarify the intent of poorly worded RIDs, and combine multiple RIDs to try to minimize the workload on the commercial partner. Only after the NASA project executive had approved the RIDS were they submitted to the commercial partner. This process ensured consistency, and prevented the partners from being overwhelmed by NASA inputs.

Partners addressed the approved RIDs by providing additional information or analysis and worked with RID submitters to ensure concerns were adequately addressed. C3PO monitored this process and became involved with closing out RIDs as necessary. This RID process became such a reliable staple that both the ISS Commercial Resupply Services contract team and Commercial Crew Program at the Kennedy Space Center requested to use the form.[213]

Milestone Review Boards

The Milestone Review Boards occurred at the partners' respective headquarters, attended by C3PO, ISS representatives, NASA Headquarters officials, and a representative from the Federal Aviation Administration. The commercial partner chaired the board. During the meeting, in addition to demonstrating completion of the milestone, the company presented information on the mission, a status of all the subsystems, and key forward work. Open RIDs were discussed, along with plans for closure. The most significant technical RIDs identified through the screening process were also presented, even if they were closed satisfactorily. This provided NASA and partner management with insight into the most significant findings of the review.

NASA utilized a number of its assets used during the Space Shuttle Program to help in performance assessment of the SpaceX C2+ mission in May 2012. The two Solid Rocket Booster Retrieval Ships, Freedom Star and Liberty Star, both carried an X-band diagnostic radar system that detects and quantifies in-flight launch vehicle behavior and any generated debris. Also on board the Freedom Star was the MARS high-powered, sea-stabilized tracking camera system that monitored the separation of the Dragon spacecraft from the Falcon 9 launch vehicle. These ships and diagnostic radar systems also helped to observe the Falcon 9 maiden flight in June 2010 and the SpaceX C1 mission in December 2010.

Unlike some reviews of previous large-scale NASA programs that routinely spanned several months, the COTS milestone reviews spanned anywhere from a few weeks to a maximum of just over two months. These thorough yet efficient reviews reflected the overall COTS operating style.

Demonstration Flights

The Demonstration Readiness Review was originally derived from the established NASA procedure for a Test Readiness Review, but also needed to encompass much of what is known as an Acceptance Review and Certification Review for hardware that NASA would have taken ownership of in a traditional contract. C3PO found aspects of these reviews were still high-value added when preparing to launch a rocket into space.

Reviewing qualification reports and acceptance test reports for lingering anomalies in hardware performance allowed for a clear understanding of the design baseline and the as-built vehicle configuration. CAT members were assigned test reports and analyses to review, and the RID form was modified to inform the project executives that the data had been reviewed and was satisfactory for flight. This helped the partner confirm that all the hardware was ready for the intended mission, and was also a key point communicated to Headquarters officials at the prelaunch briefing and mission overview.

After the Demonstration Readiness Review (the final technical review) and before the demonstration flight, additional work was needed in several areas. Multiple mission simulations occurred between the partners and NASA Missions Operations, emphasizing key elements of the

Credit: C3PO team

(Left) During both Orbital Sciences Corp. missions, NASA used its ground KTM (kineto tracking mount) cameras previously used for the Space Shuttle Program. These were deployed from the Kennedy Space Center in Florida to Wallops Island, Virginia, to monitor the launch and early ascent phase of the Antares vehicle in April and December 2013. These camera systems also helped to observe the SpaceX missions—Falcon 9 maiden flight in June 2010, C1 mission in December 2010, and C2+ mission in May 2012. (Right) NASA utilized the U.S. Navy vessel NAWC-38 to carry an X-band diagnostic radar system that detects and quantifies in-flight launch vehicle behavior and any generated debris during both launches of the Antares rocket, built by Orbital Sciences Corp.

rendezvous and berthing to ISS. The project executives took preparatory steps necessary to monitor mission success.

In the case of the first flight of the SpaceX Falcon 9 rocket, Project Executive Mike Horkachuck described how he and Assistant Project Executive Warren Ruemmele "scoured the Agency" to locate assets that could contribute additional insight into the vehicle's launch and reentry performance.[214] The launch team was able to use radar originally deployed to look for falling foam during the Shuttle launches following the Columbia accident. In addition, the Shuttle solid rocket booster retrieval ships helped monitor the SpaceX mission from sea. These additional resources allowed NASA to independently understand the launch staging events and solar array deployment, areas that historically are high risks to new vehicles.

Similarly, prior to the Orbital Antares rocket test flight, C3PO "scrounged unique devices" from around NASA to help make the mission a success.[215] These included instruments to measure the rocket's acoustic environment, as well as high-speed tracking cameras that would provide insight into any potential accidents.

Prior to the demonstration missions, all the key stakeholders, including C3PO, the ISS Program Office, and the FAA met at the respective partner's launch facility for a Mission Readiness Review to ensure all parties were ready for launch and that no open issues remained.

Shortly after the mission was completed, the partners provided C3PO with a "quick look" report, showing how the mission performed based on the data available. Several weeks later, after a more detailed report was produced, C3PO called on CAT experts to review the flight data and determine if any additional analysis was recommended. Only after all the data had been thoroughly reviewed could the partner receive payment for a successfully completed milestone.

Although the same method was applied throughout the COTS program, the circumstances of each of the commercial partners' respective development program varied according to the company's unique history, technology, and approach. Each of the three companies that C3PO partnered with is profiled in the following chapter.

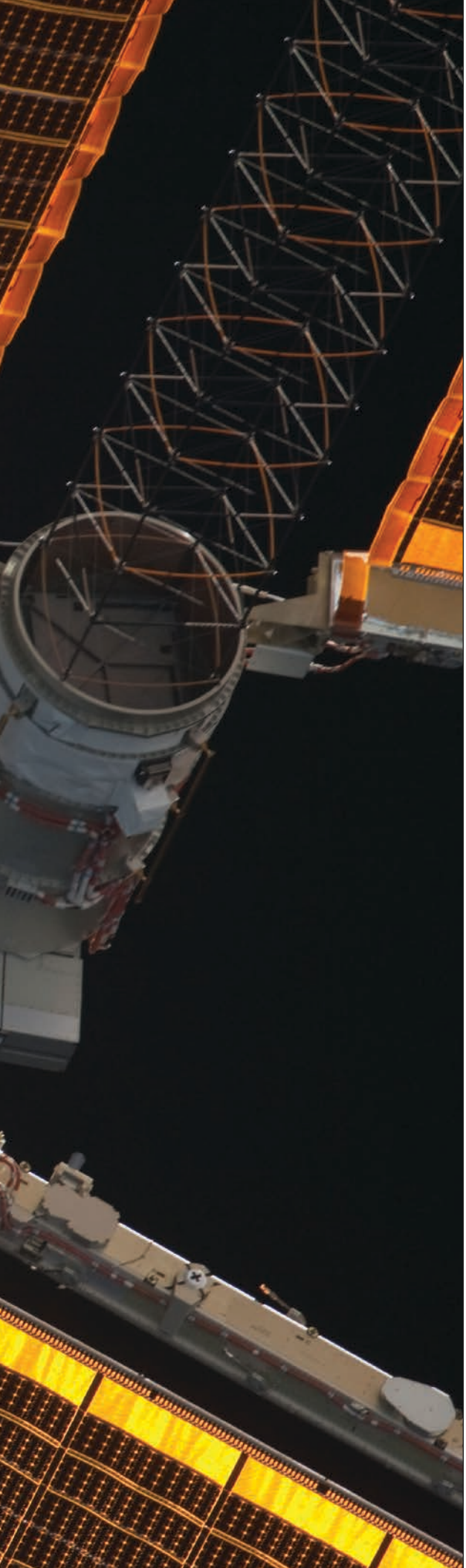
Commercial Partners

Space Exploration Technologies Corp.

Rocketplane Kistler

Orbital Sciences Corp.

chapter 5



The Commercial Crew & Cargo Program Office (C3PO) worked with three different commercial partners from 2006 through the COTS program's completion in 2013: Space Exploration Technology Corp. (SpaceX) (from 2006 to 2012), Rocketplane Kistler (from 2006 to 2007), and Orbital Sciences Corp. (from 2008 to 2013).

Space Exploration Technologies Corp.

SpaceX may be the most well-known of the three companies that were awarded funded Space Act Agreements under the Commercial Orbital Transportation Services (COTS) program. The technical triumphs of the Dragon cargo spacecraft and Falcon 9 rocket received extensive media coverage, as the company's demonstration flight to the International Space Station (ISS) in May 2012 captured national attention, encouraged by the company's active social media presence.

SpaceX had already been working on the Falcon rocket and concept for the Dragon spacecraft at the time of the first COTS Announcement in January 2006, but NASA's call to partner with commercial companies provided additional incentive to formulate vehicle specifics and turn the concept into reality.[216]

Company Philosophy

SpaceX submitted a strong business plan in its proposal, and this was among the reasons NASA selected the company as the first choice partner in the COTS Round 1 competition.[217]

Both SpaceX's business and technological strengths stemmed from its Silicon Valley-style operating philosophy, gleaned from founder, CEO, and Chief Designer Elon Musk and his entrepreneurial experience in the area of California known for development of innovative, high-risk technology ventures. Musk founded SpaceX in 2002 using his know-how and capital from a previous venture, PayPal, the secure online payment website.[218]

SpaceX's explicit aim is "to revolutionize space technology, with the ultimate goal of enabling people to live on other planets."[219] The company's innovative approach to rocketry has allowed SpaceX to achieve its near-term goals, as the company becomes increasingly competitive with major industry players such as The Boeing Company and Lockheed Martin Corp.[220]

NASA Partnership

Throughout the six years of its COTS partnership with NASA, SpaceX relied on the indispensable expertise of C3PO and the COTS Advisory Team (CAT), NASA Project Executive Michael J. "Mike" Horkachuck and Assistant Project Executive Warren P. Ruemmele in particular. With experience in Shuttle and ISS payload integration, Horkachuck was well-poised to assist the SpaceX team on their quest to develop a vehicle capable of berthing with the ISS and providing critical resupply services.

SpaceX personnel eventually came to view the project executive not as a NASA overseer, but as a vital member of their team. Horkachuck

described how SpaceX came to trust his judgment, saying, "I had a lot more history than most of the employees at SpaceX on what was going on and how things worked. When they first came in, they had the 'I know it all' kind of attitude. It took a while for them to learn that maybe they could use some help in some areas."[221]

Hans Koenigsmann, SpaceX Vice President of Mission Assurance, said, "We realized we were going through this with NASA, and they go through this with us. It's a partnership, and we're both in this. If we fail, they fail. If they fail, we fail."[222] Tim Buzza, SpaceX Vice President of Launch and Test, echoed Koenigsmann's sentiment: "The 'us and them' mentality disappeared once we got 'into the trenches,' getting the work done that both sides proposed to do. Then it was just an 'us.'"[223]

Vehicles

SpaceX worked to develop the capabilities proposed in the company's COTS proposal, beginning with A, B, and C, i.e., pressurized and unpressurized cargo delivery and return services to and from the ISS. Using the Falcon 9 rocket to launch the capsule-shaped Dragon spacecraft into low-Earth orbit, the SpaceX COTS proposal indicated it would be able to deliver 6,835 pounds of cargo to the ISS per flight, at a rate of eight flights per year.[224]

Liftoff of the inaugural SpaceX Falcon 9 launch vehicle occurred June 4, 2010, from the Space Launch Complex 40 at Cape Canaveral Air Force Station, Florida. The 227-foot rocket with 9 SpaceX Merlin engines carried a boilerplate of the Dragon spacecraft in preparation for the upcoming NASA COTS demonstration mission.

Credit: SpaceX

At the time of the COTS award, SpaceX was still developing its Falcon 1 rocket, named for the Millennium Falcon spacecraft commanded by Han Solo in the popular Star Wars film. The numeral one designated the vehicle's single Merlin engine. The two-stage, liquid oxygen- and kerosene-fueled rocket was 70 feet long, weighed 61,000 pounds, and was capable of delivering 78,000 pounds of thrust. After three failed attempts to reach orbit, the Falcon 1's first successful launch occurred on September 28, 2008, from the remote island of Kwajalein in the Marshall Islands.[225]

Hans Koenigsmann, who had previously worked as the SpaceX Vice President of Guidance and Control, described the first launch failure as "heartbreaking." "A lot of people worked a long time," he said, but "at the end, it didn't fly very far." However, Koenigsmann added, "We learned a lot of things we did wrong, and learning sometimes hurts."[226] Using the experience gained from the Falcon 1 development process, SpaceX was ready to progress to bigger and heavier rockets that relied on multiple Merlin engines.

On June 4, 2010, less than two years after the Falcon 1 launch, SpaceX successfully launched the 227 foot Falcon 9 rocket (with 9 Merlin engines), capable of generating 1,125,000 pounds of thrust at sea level, and 1,250,000 pounds of thrust in the vacuum of space.[227] Due to the expense and logistics of transporting people and materials to the Pacific, by this launch SpaceX had moved its operations from Kwajalein to Cape Canaveral in Florida. Koenigsmann explained that this way SpaceX would also be close to the company's NASA customer.[228]

Credit: SpaceX/Chris Thompson

The second flight of the Falcon 9 on December 8, 2010, met the objectives for the C1 demonstration milestone of the company's COTS Space Act Agreement, and established SpaceX as the first commercial company in U.S. history to return a spacecraft from Earth's orbit. The mission tested the Dragon's ability to be launched, maneuver in orbit, reenter, and be recovered.

On its second flight on December 8, 2010, the C1 demonstration mission of the company's Space Act Agreement, the Falcon 9 carried the first SpaceX Dragon spacecraft to orbit, after which it successfully reentered, splashed down, and was recovered.

Dragon features a recoverable capsule and disposable "trunk" for unpressurized cargo. In total, the vehicle is capable of ferrying 13,228 pounds of upmass and 6,614 pounds of downmass to and from low-Earth orbit. The spacecraft propels itself in space with the use of 12 to 18 Draco thruster engines, and relies on a PICA (Phenolic Impregnated Carbon Ablator) thermal protection system to protect the capsule during reentry to Earth's atmosphere.[229]

Musk reputedly named the spacecraft after the 1963 song "Puff, the Magic Dragon," in response to critics' skepticism that the startup company would be able to achieve its goals. The company also displayed a sense of humor with the C1 mission's "top secret" payload of a wheel of cheese, in reference to a Monty Python comedy skit.[230]

Off-the-Shelf

SpaceX developed its technologies using a business model that fits many of the observations on disruptive technology found in *The Innovator's Dilemma*, the book that venture capitalist Alan Marty recommended to the C3PO team to help them understand how large organizations can nurture internal innovation. For example, the statement that "generally disruptive innovations were technologically straightforward, consisting of off-the-shelf components put together in a product architecture that was often simpler than prior approaches," describes the company well, despite the fact that the book was published years before SpaceX was founded.[231]

SpaceX made widespread use of off-the-shelf hardware in developing its first launch vehicle, the Falcon 1 rocket. Engineers found these readily-available components to be significantly cheaper and equally reliable as space-specific hardware. As reported by *Fast Company* in 2005, the SpaceX Falcon 1 would use an Ethernet bus for communication between the rocket's different computers. "I didn't want to invent anything new," explained Hans Koenigsmann.[232]

Other examples included components of avionics equipment such as satellite navigation and a readily-available airbag from Musk's electric car venture, Tesla Motors, Inc. For the crewed variant of the Dragon spacecraft, SpaceX utilized a modified bathroom stall latch for securing cargo lockers and NASCAR five-point harness restraint seatbelts for astronauts—both off-the-shelf items that cost significantly less to purchase and were more comfortable for crew use than their much more expensive space-rated counterparts.[233]

Small Organization

SpaceX was also able to pursue innovation by virtue of its small organization. With less than 100 employees at the time of the COTS award in 2006, communication flowed easily between team

members.[234] John Couluris, Senior Director of Launch and Mission Operations at SpaceX, described how employees were trusted to execute their jobs without disproportionate oversight, thus streamlining the development of new designs and hardware.[235] Issues were easily resolved with a simple face-to-face conversation, and design changes could be quickly communicated to colleagues in manufacturing.

This was even more true in 2008, when SpaceX moved from a group of separate buildings and facilities in El Segundo, California, to a large factory in the neighboring south Los Angeles suburb of Hawthorne on Rocket Road, where development and manufacturing could be completed under one roof—a roof that used to cover Boeing operations, and before that served as the original home of The Northrop Corp. formed in 1939.

This sense of close camaraderie sometimes extended beyond work hours. While on Kwajalein, employees also benefited from days and weeks spent together in the Marshall Islands.

Technicians inside a processing hangar at Cape Canaveral Air Force Station, Florida, guide the SpaceX Dragon as it is lifted atop its cargo ring. The spacecraft is designed to carry both pressurized and unpressurized cargo to the ISS and safely return cargo to the Earth.

Credit: NASA/Kim Shiflett

In addition to their work, teams spent much of their limited off-time in close proximity as they commuted between islands and, for lack of many other activities or distractions, fishing and diving together.[236]

Design and Manufacturing

Project Executive Mike Horkachuck observed that in contrast to traditional NASA methods of development in which a vehicle is designed to optimal levels of performance before assembly and testing, SpaceX built some additional margin and "robustness" into its design from the beginning. Then, vehicles could be more easily altered and optimized after tests provided demonstrable measures of their performance.[237]

SpaceX also stuck closely to its philosophy of pursuing a thorough test program. The company conducted a test of every Merlin engine at its rural McGregor, Texas, facility (an existing test pad purchased from defunct Beal Aerospace) as close to flight conditions as possible. Using reimbursable Space Act Agreements, in which SpaceX paid NASA for its services, the company also relied on NASA facilities such as the Marshall Space Flight Center in Huntsville, Alabama, for services like wind tunnel testing of the Falcon 9 first stage.[238]

As SpaceX matured as a company over the course of its partnership with NASA, it also increasingly shifted to manufacturing more of its own components in-house at the Hawthorne facility. In many cases this strategy helped the company deliver the same or better quality while saving money, particularly when vendors charged prices the company deemed too high.

Credit: SpaceX/Roger Gilbertson

SpaceX worked closely with NASA's Ames Research Center to develop PICA-X, a SpaceX variant of NASA's Phenolic Impregnated Carbon Ablator (PICA) heat shield. Under a reimbursable Space Act Agreement, NASA made its expertise and specialized facilities available to SpaceX as the company designed, developed, and qualified the heat shield. Dragon's PICA-X protected the spacecraft during reentry.

SpaceX also made a point of using American companies as suppliers whenever possible—in contrast to its competitor Orbital, which preferred an international collaboration.

One of the most prominent examples of the company's manufacturing capability is PICA-X, SpaceX's version of the heat shield material developed in cooperation with NASA Ames Research Center. (Ames developed and patented the original PICA material in the 1990s.) By developing its own material for Dragon's thermal protection system, SpaceX also avoided the risk of potential price manipulation that can result from reliance on a single-source supplier.[239] In fact, during the COTS competition, NASA identified the company's in-house capabilities as a major strength of the company's proposal, as they allowed for "improved project control and simplified interfaces/integration."[240]

Credit: SpaceX

SpaceX conducts rigorous tests on its engines at its McGregor, Texas, rocket-development and test facility that originally had been developed by Beal Aerospace. SpaceX refitted the largest test stand for the full Falcon 9 engine firing (pictured above). Also at this location are new test stands, a vacuum chamber to test the Draco thrusters, and buildings where employees de-fuel and clean up the flown Dragon spacecraft and potentially refurbish it for reuse.

Milestones

In August of 2006 NASA awarded SpaceX its COTS Space Act Agreement worth $278 million, to be paid in increments upon successful milestone completion, to develop the capability to deliver and return cargo to and from low-Earth orbit.[241] Musk had always envisioned a system capable of transporting humans—not only cargo—across the solar system, but the first step was ferrying supplies to the ISS (though the vehicles were designed for robustness from the beginning, with an eventual human rating in mind). Human transportation to low-Earth orbit, COTS Capability D, was included as an option in the SpaceX SAA (one that NASA never exercised).

SpaceX executed the 40 total milestones of its Space Act Agreement between August 18, 2006 (the date NASA signed the agreement) to May 2012, when SpaceX successfully completed the objectives of the company's final COTS mission to berth with the International Space Station. That August, NASA completed its verification that this milestone's objectives had been met.

Financial Milestones

By March 2009, SpaceX had completed the three financial milestones that proved the company could contribute its promised share of the funding needed to finish development of the Falcon 9 and Dragon vehicles. NASA placed these financial markers early in the program to allow the space agency to exit the agreement early, should it become necessary, before expending excessive monies on an unsuccessful development program. In addition to his own resources, Musk was able to turn to his network of colleagues in Silicon Valley to lead the subsequent rounds of financing that made it possible to forge ahead with the COTS agreement.[242]

However, SpaceX did experience financial struggles. Looking back, President Gwynne E. Shotwell described her biggest challenge as seeking investors and convincing potential customers to purchase launch services before SpaceX was able to demonstrate the capabilities of the Falcon vehicles. "I was focused on keeping the company alive, keeping people paid while we were struggling and getting through it," Shotwell said.[243]

Technical Milestones

Paper-based milestones (System Requirements Reviews, Preliminary Design Reviews, Critical Design Reviews, and Demonstrated Readiness Reviews) and other technical milestones (for example engine tests and a cargo integration demonstration) took place as intermediate steps to the three primary COTS demonstration missions.

The C1 mission on December 8, 2010, tested the Dragon's ability to be launched, maneuver in orbit, reenter, and be recovered. Moments after the SpaceX C1 demonstration mission lifted off the pad, members of C3PO monitoring from the partner launch control center in Florida leapt from their seats to run outside and watch the rocket clear the tree line, lifting into orbit. After two orbits and a successful splashdown, the engineers gave each other thunderous high fives—with a few receiving a champagne shower.[244]

NASA also deployed its Shuttle-launch debris radar and Shuttle solid rocket booster retrieval ship assets to observe the reentry of the SpaceX C1 capsule, the first U.S. commercial vehicle to reenter from space. This and the parachute deployment were some of the most critical aspects of the SpaceX C1 mission. These assets also would have provided invaluable information in the case of an in-flight anomaly.[245]

The next milestone mission, C2, would comprise a Dragon launch and flyby of the ISS, while C3, the final milestone, would complete the berthing and cargo delivery demonstration.

Schedule Slips

SpaceX's original schedule proposed to complete all milestones by September 2009. As the milestones

transitioned from more paper-based benchmarks—i.e., financing rounds and design reviews—to the building of physical hardware, milestone completion began to slip behind the original, very aggressive schedule. Eventually schedule slips resulted in a cumulative delay of approximately two and a half years, and the final demonstration mission originally planned for September 2009 did not occur until May 2012.

According to Horkachuck, as these milestones began to slip, SpaceX became fearful that NASA would terminate the company's Space Act Agreement. Article 17B of the SAA did allow for "Termination for Failure to Perform," but did not specify the consequences in the case of schedule delays.[246] However, C3PO determined that as long as SpaceX was making technical progress and had a sound plan to continue in the face of delays, there was no need to end the partnership.

Both SpaceX and NASA knew at the time the Space Act Agreements were signed that the company's schedule was aggressive and pushed the time limits of what it was possible to achieve in rocket science. According to C3PO Manager Alan J. Lindenmoyer, "The average time to field a new launch vehicle is at least 27 months longer than initially projected." Lindenmoyer observed "that's almost exactly the delay that SpaceX experienced from the predicted original launch date of the first demonstration flight to the actual."[247] Therefore, NASA expected these slips from the beginning.

Augmentation Milestones

Partially as a result of these delays, and to increase mission safety and assurance, in fiscal year 2011 Congress appropriated an additional $300 million to the Commercial Crew & Cargo Program Office, allowing $118 million in supplementary funds to be given to each of the commercial partners.

Eighteen milestones were added to the SpaceX Space Act Agreement, which concentrated on seven main tasks specifically targeted to risk reduction: a pressurized cargo environment modal test; Light Detection and Ranging (LIDAR) sensors testing; solar array deployment tests; a spacecraft thermal vacuum system test; infrastructure enhancements (launch, test and production sites); acoustic and electromagnetic interference (EMI) tests; and enhanced powered cargo accommodations.[248]

According to Shotwell, several of these, such as the thermal vacuum and EMI testing, were tests that SpaceX had proposed as part of the original agreement but were removed after negotiations because cost exceeded the available NASA funds under the original COTS $500 million budget allocation.[249]

Flexibility

As with any rocket development program, unforeseen issues and deviations from original projections were bound to occur. Some of these changes were suggested by NASA, based on its experience and lessons learned from past programs, while others SpaceX proposed in order to achieve greater efficiency and accelerate development. Regardless of which party proposed the changes, both partners were willing to work towards for the best possible solution.

For example, after the development of Falcon 1, SpaceX originally planned the Falcon 5 as an intermediate step to a launch vehicle with more capability. However, as a result of NASA's ISS cargo needs, SpaceX decided to pursue the Falcon 9, with nine Merlin engines.[250] In addition to hardware, NASA also influenced some of the company's processes and procedures. Horkachuck influenced SpaceX team members to place greater emphasis on building integrated schedules as

Credit: SpaceX

Prior to its inaugural launch, the Falcon 9 rocket undergoes its final integration in the hangar at SpaceX's Cape Canaveral launch site in Florida. Components include: Dragon spacecraft qualification unit (left), second stage with Merlin vacuum engine (center), first stage with nine Merlin 1C engines (right).

Credit: C3PO team

NASA C3PO team members toured the company's launch site before the first SpaceX demonstration mission to the ISS in May 2012. Attending were (left to right): Andrea Riley, NASA Headquarters Assistant Program Executive; Todd Hegemier, C3PO Financial Team; Lisa Price, C3PO Financial Team; Mark Timm, NASA Headquarters Program Executive; Alan Lindenmoyer, C3PO Manager; Alan Marty, C3PO Business Advisor; Phil McAlister, NASA's Director of Commercial Spaceflight Development; Dennis Stone, C3PO Integration Manager; and Allison Zuniga, NASA Headquarters Strategic Planning.

a critical project management tool.[251] Similarly, through its partnership with NASA, SpaceX began to put into place a more rigid and thorough documentation and configuration management process.

Horkachuck strongly encouraged SpaceX to develop its own communications system with ISS, instead of relying on the existing Japan Aerospace Exploration Agency system. Horkachuck observed that the SpaceX operating style was not compatible with the methodical way of business that he noted was typical of Japanese companies. The resulting COTS UHF Communications Unit (CUCU) system gave SpaceX control of its own development and schedule, and allowed it to learn more about how to build and verify hardware to the standards and requirements of ISS. This included an introduction to the Safety Review Panel process before the first full demonstration mission.[252]

Based on his experiences with past programs, Horkachuck was also able to intercede when SpaceX moved to its new facility in Hawthorne. He noticed issues during the production of the first few rockets and spacecraft and "kind of forced some of [the NASA] money to be spent on fixing problems" in some of those areas.[253] NASA also helped with an additional friction stir welder, and some other production capabilities that would make a significant difference in manufacturing processes.

Another specific area of influence was additional parachute drop tests, in this particular case applying some lessons learned from delays in NASA's Orion Crew Exploration Vehicle Program. Resources and lessons learned from the Space Shuttle Program were also applied, as SpaceX utilized the NASA Shuttle launch debris radar systems to study the ascent phase of the Falcon 9.[254]

SpaceX was also able to take advantage of two Space Shuttle flights to test its rendezvous and proximity operations systems. In July 2009, STS-127 launched with a DragonEye Detailed Test Objective (DTO) box on *Endeavour's* Space Station docking system. As the Shuttle approached the ISS, the DTO tested the company's flash LIDAR sensor. As opposed to a traditional scanning LIDAR, the system works by sending a single laser pulse to a target (as opposed to thousands of multiple pulses required by a scanning LIDAR system), and measuring the time it takes for the signal to bounce back. A similar test of the Dragon LIDAR system took place two years later on STS-133, the final flight of Space Shuttle *Discovery*.[255] According to Warren P. Ruemmele, NASA Assistant Project Executive for SpaceX, these tests "allowed SpaceX to perform the best possible in-space test of the … LIDAR they would eventually use" on the final demonstration mission to Station.[256]

NASA influences did not mean SpaceX did not push back with its own ideas of how to facilitate vehicle development. Even in the matter of documentation, which employees acknowledged as important, SpaceX more often relied on electronic and interactive procedures rather than hard copies.[257]

One of the major changes made as time progressed was the combination of the C2 and C3 milestone missions. As C3 was essentially a continuation of the C2 mission, in 2010 SpaceX proposed to NASA that instead of conducting the demonstrations as two separate missions and building two separate spacecraft, that after the C2 objectives were completed NASA would allow SpaceX to complete the C3 objectives (of ISS grapple and berthing) on the same mission.

NASA initially hesitated, viewing the proposal as an attempt to eliminate cost while taking on an unacceptable amount of risk, but eventually acquiesced—with the provision that Dragon remain in space a few additional days and perform some system checkouts to allow for some of the planned C2 mission time and objectives. Negotiations lasted several months, but in the summer of 2011 the Associate Administrator for the Human Exploration and Operations Directorate, William H. "Bill" Gerstenmaier, approved the change to

the company's Space Act Agreement. A single C2+ mission allowed SpaceX to complete both the C2 and C3 milestone objectives on a single flight (but with the understanding that the C3 mission could still be flown as a separate mission if SpaceX failed to achieve all the C2 objectives during the first attempt).[258]

This amendment to the SAA milestones demonstrated NASA's commitment to work with partners and negotiate, as opposed to imposing its will, traditions, and procedures on the companies, and proving that the COTS team was truly open to suggestions on how to make this new way of doing business work. Partners were not only welcomed but encouraged to push back on any requirements for requirements' sake, resulting in what all parties agreed was a more successful and cost-effective mission overall.[259]

Not Always a Winner

It should be mentioned that, despite SpaceX's inarguable success, there were some NASA awards SpaceX did not win. After the SAA with RpK was terminated in October 2007, SpaceX was one of 13 companies to submit a proposal for the remaining $170 million of available COTS funds. However, SpaceX was eliminated in the first round of selection.[260]

SpaceX had a following opportunity to receive additional funding from the Commercial Crew & Cargo Program when the Commercial Crew Development (CCDev) competition was announced in August 2009 to begin work on the capabilities that would be necessary for industry to ferry people to and from low-Earth orbit. The 2009 American Recovery and Reinvestment Act allocated $400 million for space exploration-related activities, of which $50 million was allocated to the CCDev project administered by C3PO.

SpaceX made it through the first round of eliminations, but when the Participant Evaluation Panel made its final decision in December 2009 it deemed that the company asked too high a contribution from NASA, and the proposal was not a good use of designated stimulus funds for technology that would be developed in return.[261]

C2+ Demonstration Mission

In the end, NASA's partnership with SpaceX succeeded in producing U.S. cargo capability to low-Earth orbit. After months of training with ISS astronauts and a few launch delays to ensure issues such as flight software testing had been resolved, SpaceX launched the Dragon C2+ spacecraft from Cape Canaveral, Florida in the early hours of the morning on 22 May 2012.[262] The first three days of the mission were spent demonstrating the objectives of the original C2 mission, establishing communications with the ISS using the COTS UHF Communications Unit (CUCU) and conducting an ISS flyby.

Then, on May 25, 2012, the NASA Mission Control team in Houston granted Dragon permission to begin its approach toward the ISS. In a tense moment just prior to the final approach for grapple, Dragon experienced an issue with its thermal imagers caused by a reflection from the Japanese Experiment Module, resulting in a discrepancy between the LIDAR and thermal imagers. Forging ahead without consistent readings would have triggered a

Credit: NASA/Alan Ault

During the early morning hours of May 22, 2012, the SpaceX Falcon 9 launched from Cape Canaveral Air Force Station, Florida (top photo), to begin the C2+ demonstration mission, the final phase of its COTS Space Act Agreement. On board was the Dragon spacecraft with more than a thousand pounds of cargo to deliver to the ISS. Following a series of tests of its maneuverability and abort systems, the Dragon was grappled (bottom photo) and berthed to the International Space Station by the crew members of ISS Expedition 31. After 5 days, 16 hours, and 5 minutes, the Dragon was released.

Credit: SpaceX

Employees outside the mission control room at SpaceX headquarters in Hawthorne, California, waited while the Dragon spacecraft successfully berthed with the International Space Station on May 25, 2012. Over its six-year COTS partnership with NASA, the company that was founded in 2002 transitioned from a small startup to the first private company to deliver cargo to the ISS.

NASA abort, so SpaceX mission control in Hawthorne ordered a retreat and quickly engineered a solution. Software programmers narrowed the LIDAR's field of view to eliminate the reflection, then uploaded the software change to Dragon, allowing the spacecraft to continue its approach and NASA to give the final "go" command for capture.

ISS Expedition 31 astronaut Donald R. Pettit grappled the spacecraft at 13:56 GMT, followed by a successful ISS berthing. Shotwell, who called the event "amazing" and "extraordinary," celebrated with the close to 1,500 employees who had waited outside the company's mission control room at SpaceX headquarters during the early morning hours.[263] After delivering 1,014 pounds of cargo, Dragon unberthed from the ISS and splashed down in the Pacific Ocean on May 31, 2012, signaling the completion of its Space Act Agreement with NASA. All that remained were formal reviews to verify that all the mission objectives had been achieved.[264]

After the successful mission, SpaceX began the transition from development of the Dragon spacecraft and Falcon 9 launch vehicle to manufacturing and operations for contracted flights. Development continued on projects such as a manned Dragon spacecraft for the NASA Commercial Crew Program, and bigger and more powerful rockets. These launch vehicles—including the Falcon 9 version 1.1, Falcon Heavy, and Grasshopper vertical landing vehicle—stemmed from the lineage of the original Falcon 1 launched on a remote island in the middle of the Pacific. That same heritage allowed SpaceX to provide needed cargo to the ISS, eventually graduating from less-critical supplies to scientific experiments carrying live animal specimens.[265]

Over the six-year course of the company's Space Act Agreement, NASA contributed both financial and technical assistance to the development of the SpaceX Falcon launch vehicle and Dragon spacecraft. However, as both C3PO Manager Alan Lindenmoyer and SpaceX President Gwynne Shotwell emphasized, the company's financial contribution exceeded the government's for the work performed under the COTS program. While the COTS office distributed a total of $396 million to the company (the original $278 million agreement plus $118 million in augmentation funds), SpaceX financed approximately $454 million, over half of the total amount, to make the program a success.[266]

NASA's technical advice is less quantifiable, but the following statement by Tim Buzza gives an indication of how closely the government and private partner worked together: "There's no doubt

Credit: SpaceX/Michael Altenhofen

On May 31, 2012, the capsule-shaped Dragon splashed down in the Pacific Ocean west of Baja California, Mexico, less than one mile from the center of the targeted landing zone. SpaceX recovery teams retrieved the vehicle carrying cargo returned from the ISS.

Credit: NASA/Bill Ingalls

On June 13, 2012, NASA Administrator Charlie Bolden (left) and SpaceX CEO and Chief Designer Elon Musk inspected the Dragon spacecraft that returned to Earth and had been moved to the SpaceX facility in Texas. After its 9-day test flight, the vehicle returned with nearly 1,400 pounds of equipment and experiments from the ISS.

that through years of working together, fingerprints of meetings and discussions with NASA have ended up on the rocket."[267]

SpaceX has transitioned from a small startup company to an increasingly major contender in the aerospace world in large part thanks to NASA's partnership. After the C2+ mission, Elon Musk acknowledged what a "tremendous honor" it had been to work with NASA, saying, "We could not have started SpaceX, nor could we have reached this point without the help of NASA."[268]

With the final demonstration mission, SpaceX sealed its place in history as the first ever private company to deliver cargo to the International Space Station.

Rocketplane Kistler

Rocketplane Kistler (RpK), the second commercial partner selected in the Round 1 COTS competition, found itself unable to execute the terms of its Space Act Agreement due to the formidable challenge of securing the financing to fund a successful aerospace venture.

K-1 Vehicle

The Kistler Aerospace Corp. was founded in 1993, one of several aerospace startup companies established after the end of the Cold War to lower the cost of launching small-sized satellites into low-Earth orbit.[269] In 1995, Dr. George E. Mueller, Director of NASA's Apollo Program and an early champion of the Space Shuttle, joined Kistler as the company's CEO, and the company began development of the Kistler K-1 vehicle.

The design for the K-1 had its roots in the early concepts for a fully-reusable space transportation system Mueller had envisioned in the late 1960s. However, due to budget cuts and political maneuvering in the 1970s, the Space Shuttle that NASA eventually developed was only partially reusable; the orbiter and solid rocket boosters were recovered and refurbished for reuse, but the external tank was discarded after every mission.

The K-1 promised to convert the dream of a fully reusable vehicle to reality, as both stages of the vehicle would glide back to Earth using a system of parachutes and air bags. Operating in two stages, the K-1's first stage Launch Assisted Platform (LAP) would carry the second stage Orbital Vehicle (OV) to its trajectory in low-Earth orbit. The liquid oxygen/kerosene-fueled LAP would be powered by three Aerojet AJ-26 engines (refurbished Russian NK-33s)—the same engines used by Orbital in its Antares rocket.[270]

Kistler planned to launch the 113-foot tall K-1 vehicle from the Woomera Test Range in a sparsely populated area of South Australia.[271] After delivering its cargo to orbit, the LAP would return to Earth for rapid turnaround at the company's horizontal processing facilities. The company's 2006 COTS proposal outlined how the OV could be configured to transport about 50,050 pounds of cargo per year or up to five crew members for Capability D.[272]

In addition to Mueller, Kistler boasted an impressive executive team, with decades of combined NASA

Credit: KAS

Rocketplane Kistler planned to use the K-1 launch vehicle, in development since 1995, in its partnership with NASA. The fully reusable vehicle had two stages with the second stage, the Orbital Vehicle (above), designed to transport cargo or crew. The company was unable to meet its financial agreements, resulting in a termination of their COTS Space Act Agreement.

Credit: C3PO team

Walter Kistler, left, cofounder of Kistler Aerospace and K-1 inventor, joined with members of the COTS Participant Evaluation Panel for a presentation during the NASA due diligence visit with Rocketplane Kistler as part of the 2006 COTS competition.

experience in the Apollo, Shuttle, and Space Station programs. Randolph H. "Randy" Brinkley, Kistler's President, served as the NASA Program Manager of the International Space Station from 1994 to 1999. Brinkley explained that one of his primary reasons for joining the Kistler venture was to sustain the ISS as a laboratory: "I had such strong feelings about being able to make the Space Station—the science platform that we spent $100 billion on—to enable it. I saw that the K-1 had that capability."[273]

Joseph W. "Joe" Cuzzupoli served as Kistler's Vice President and K-1 launch vehicle Deputy Program Manager, bringing to the table his years of experience as Rockwell's Assistant Manager of the Apollo Program and Vice President and Program Manager of the Space Shuttle Orbiter.[274] COTS Project Executive Bruce Manners later reflected that Cuzzupoli "had so much experience, so many guidelines," that "it was just a real career highlight to have the opportunity to meet and work with somebody of his caliber and his background."[275] Rounding out the team, Richard H. "Dick" Kohrs, another former NASA manager with decades of experience in the Apollo, Space Shuttle, and Space Station programs, was Kistler's Chief Engineer.

The Kistler Aerospace Corp. originally aimed to develop the K-1 independently of any government funding. In 1997, Kistler won a $100 million-plus contract to deliver 10 satellite launches for Space Systems/Loral, "but the deal hinge[d] on Kistler's ability to finance and build its planned K-1 rocket."[276] Years later, the company's ability to attract and retain funding would linger as an issue for what was otherwise an advanced technical concept.

Space Launch Initiative

At the turn of the 21st century, Kistler Aerospace increased its involvement in government programs. In May 2001, NASA awarded Kistler Aerospace one of 22 Space Launch Initiative contracts, designated for small businesses, to study the feasibility of commercial cargo transportation to the International Space Station. Kistler would only receive $10 million of its $135 million award until the K-1 vehicle flew a successful mission.[277]

Only two years later, on 15 July 2003 Kistler filed for Chapter 11 bankruptcy protection, unable to pay over $600 million in debt to the company's creditors. Kistler turned to the New York hedge fund company Bay Harbour Management LLC to help the company out of debt. Bay Harbour became the majority owner of Kistler Aerospace, and was tasked with the job of raising the $450 million Kistler estimated it would need to complete the K-1 vehicle. At the time, Kistler predicted it could complete development of the K-1 within 13 to 18 months of receiving sufficient financing.[278]

Although NASA had cancelled the Space Launch Initiative program in 2002, in February 2004, NASA announced its intent to reactivate the previous award and offer Kistler a sole-source contract for pre- and post-flight data from the K-1 vehicle. NASA justified the award of Kistler's no-bid award on the grounds that no other company had a vehicle as near completion as the K-1.

By 2004, Kistler had completed 75 percent of the vehicle's hardware, 85 percent of the design, and 100 percent of the software for guidance, navigation, and control. Presaging NASA's future use of funded Space Act Agreements, NASA would provide payments to Kistler only after data was delivered, and any potential contracted ISS missions would be subject to a separate follow-on procurement.[279]

However, a recent startup founded in 2002, SpaceX, protested the award at the Government Accountability Office, claiming that the contract should have been subject to open competition as per standard Federal Acquisition

Regulation procedures.[280] SpaceX won the protest, and after losing their award Kistler again failed to raise the money it needed to complete the K-1 vehicle. The company was "put on the shelf" by Bay Harbour, still the majority owner.[281]

COTS

In 2005, as interest in NASA's new way of doing business began to circulate among commercial space transportation companies, George D. French, the owner of Pioneer Rocketplane, a suborbital space tourism venture based in Oklahoma, attended the COTS Industry Day in Houston. French reported that he met investment banker Petter Kleppan at the bar of a local hotel, who suggested that French buy the failing Kistler Aerospace Corp.[282]

In February 2006, French announced the purchase of Kistler Aerospace, giving the new Rocketplane Kistler Inc. about six weeks to pull together a team and prepare a COTS proposal for the March 3, 2006 deadline.[283] As one of the company's two speakers during the final selection briefings at NASA Headquarters, Mueller presented a strong case for the advanced state of the K-1's technological development, and on August 18, 2006, NASA selected RpK as one of two commercial partners in the first round of the COTS competition, though noting the weak point of the company's financial plan.[284]

Milestones

Despite the company's impressive technical credentials, Rocketplane Kistler struggled to achieve the financial objectives defined in the company's Space Act Agreement with NASA.

Technical Milestones

Rocketplane Kistler easily achieved its first two technical milestones, the Program Implementation Plan and System Requirements Review.[285] Both were completed on schedule, in September 2006 and February 2007 respectively. The RpK team was technically proficient, well on the way to achieving their next technical milestone, the Pressurized Cargo Module Critical Design Review, except for the issue of financing.

Financial Milestones

The financial milestones presented more of a struggle for RpK. The company required 30 additional days to complete its first round of financing, $40 million originally due by the end of September 2006. Rocketplane Kistler hired investment bank Jeffries Quarterdeck LLC to help it raise the capital needed to complete development of the K-1 vehicle. Jeffries Quarterdeck convinced RpK that all its funds should be secured in one large lump sum, and in late February 2007, NASA amended the RpK Space Act Agreement to accommodate this new plan. The original Milestone 4 ($120 million in financing due February 2007) and Milestone 9 ($256 million in financing due February 2008) were combined. The consolidated Milestone 4 called for $500 million of financing to be secured by May 2007.[286]

Jeffries helped RpK prepare a Confidential Information Memorandum about the company and its business plan to show to interested lenders. RpK went to New York City in April 2007 to find potential investors, particularly a lead investor that could provide over $100 million of funds and help monitor RpK's progress for the other possible financiers. One of RpK's investors from the first round

Credit: C3PO team

C3PO Manager Alan Lindenmoyer approved payments to Rocketplane Kistler upon completion of technical milestones. Although technically proficient, the company failed to meet its financial commitments under the COTS Space Act Agreement with NASA.

of financing, MacDonald, Dettwiler, and Associates (MDA), brought in the Ontario Teachers' Pension Plan (OTPP) as a lead investor willing to contribute over $200 million of financing. Having reached the significant landmark of $300 million raised (the sum of the existing $100 million plus $200 million from OTPP), RpK continued its search to reach the full $500 million.[287]

Throughout the process, the COTS team supported RpK's endeavors. Venture Capitalist Alan Marty and Dennis A. Stone met with the RpK board at the company's facilities in Wisconsin and attended RpK meetings on Wall Street.[288] Project Executive Bruce A. Manners and Program Manager Alan J. Lindenmoyer also helped review RpK presentations and accompanied RpK during their July 2007 "Investor Day" in New York. The NASA representatives helped demonstrate NASA's commitment to the COTS program, explaining to investors the Agency's new way of doing business.

Marty helped explain the investment process and advise C3PO on which investors might be more willing to commit to a financial contribution. Attorney Jonathan A. Arena was also present to ensure NASA did not cross any legal or policy boundaries by issuing a particular endorsement of the company, and clarifying that participation in the COTS program was not a guarantee of a follow-on service contract.[289]

Both Marty and Arena used their expertise to serve as liaisons between financial, legal, and engineering groups in the NASA, commercial, and private investment communities. Arena later described how "one of my informal roles throughout that COTS process was being a translator, explaining some of the legal aspects to the engineers, some of the business aspects to the engineers, and trying to be a go-between between folks who have vastly different backgrounds."[290]

Termination

Despite these efforts, by May 2007 Rocketplane Kistler still had not managed to attract all $500 million needed to complete the revised Milestone 4 of the company's Space Act Agreement. NASA agreed to an extension until July 2007, noting that the company had identified a lead investor. However, by July RpK had raised only $300 million, $200 million short of the amount needed for completion of the milestone that had originally been due two months prior. Without the financing needed to continue development, RpK began to slip on its technical progress.

In August 2007, Manners recommended that NASA issue notice of termination, giving Rocketplane Kistler 30 more days to secure financing to allow the company one final chance to meet its second financial milestone.[291] NASA decided to end RpK's association with the space agency only after a series of intense discussions with RpK and the COTS team's legal and financial advisors, ultimately determining that RpK did not have a viable chance of raising the required funding.[292]

Associate Administrator for the Exploration Systems Mission Directorate Scott J. "Doc" Horowitz explained, "I basically used a three-strike policy. They didn't meet their milestones. We tried, now we'll go on."[293] Horowitz issued NASA's 30-day notice of termination to RpK on September 7, 2007, and on October 18, 2007, the company's Space Act Agreement was formally terminated. Only four days after the official termination, NASA issued the COTS Round 2 Announcement to select a new commercial partner.

Throughout the termination process, NASA remained in close communication with Rocketplane Kistler. Correspondence between Lindenmoyer and Brinkley reveals how RpK tried to argue the company's case. From the company's perspective, NASA's failure to guarantee the follow-on Commercial Resupply Services contract during RpK's search for funding was the primary reason for the company's inability to find investors willing to commit money to the project.

Without a defined NASA commitment to buy the company's low-Earth orbit transportation services, financiers had no guarantee of a return on their investment. Investors' hesitance could also be explained by the long development time and high risk inherent in space ventures; with the dozens of proposals investors regularly sift through, as exciting as the prospect of space travel was, investors' focus was ultimately on the bottom line.[294]

According to Brinkley, Rocketplane Kistler was also unfortunate in the timing of its appeals to investors. To begin with, in April 2007 NASA announced a $719 million extension of the space agency's contract with the Russian Federal Space Agency (Roscosmos) to provide crew and cargo services through 2011, signaling to investors that NASA would not be relying on U.S. commercial resupply services in the foreseeable future. Then, when the Space Operations Mission Directorate at NASA Headquarters in Washington, DC, issued a Request for Information in the summer of 2007 to gather information to help plan for an eventual services contract, the ISS Program Office indicated it planned to commit to only three servicing missions—resulting in a significantly smaller figure than the billion-dollar-plus Commercial Resupply Services (CRS) contracts that were actually awarded in December 2008, and not one large enough to convince investors.[295]

Next, after the July 4 Independence Day holiday, RpK encountered difficulty contacting venture capitalists on Wall Street, many of whom took summer vacations and were not fully available until September.[296] RpK's search for investors also coincided with the U.S. subprime mortgage crisis that began its deleterious effect on U.S. stock markets in the summer of 2007. Said French, "Never in my risk assessments did I put on my plate that the hedge funds…that were demanding a 15 percent return from us were investing in packaged home mortgage loans to the tune of billions of dollars."[297] After the markets collapsed, the company was unable to resume talks with investors.

Credit: C3PO team

NASA and Rocketplane Kistler (RpK) representatives discussed progress of the company's milestones during a meeting held at the Michoud Assembly Facility, New Orleans, Louisiana. RpK used the facility to assemble and check out its K-1 Space Transportation System after entering into a reimbursable Space Act Agreement with the NASA Marshall Space Flight Center in Alabama.

Finally, also at issue was the fact that two of Rocketplane Kistler's primary investors, MDA and OTPP, were foreign-owned entities. Brinkley explained in his correspondence with Horowitz that "[OTPP's] participation was limited, in part, by the fact that it is a Canadian fund and NASA's view that a Canadian fund could not have a controlling position in RpK without violating the Commercial Space Act [of 1998]."[298] In his letter, Brinkley went on to point out the irony of NASA's position in this case, since the Agency was dependent on foreign vehicles for ISS resupply and crew transport.

Epilogue

After the company's termination, Brinkley attempted to convince officials at NASA Headquarters to retain some of the valuable hardware and intellectual property from the K-1 vehicle, as the company was no longer able to afford storage at the NASA Michoud Assembly Facility in New Orleans, Louisiana. Brinkley reported how he argued that there was "real value in keeping that work that had been done, and that it was a shame to just have that become scrap," especially after NASA had invested so much government money in the K-1 development.[299]

Company owner George French was able to transport some hardware pieces to storage facilities in California and Green Bay, Wisconsin, though the majority were eventually scrapped. Regarding the intellectual property of the K-1 design, NASA still retains the right under the terms specified in the Space Act Agreement to use any information RpK submitted as part of any of the three milestone reviews the company completed. However, there have been no attempts at the space agency to exercise this right.[300] Rocketplane Kistler did attempt a GAO protest of the Round 2 COTS competition, but was unsuccessful.

Rocketplane Global, the parent company of Rocketplane Kistler, filed for Chapter 7 bankruptcy on June 15, 2010 (along with its owner).[301] In December 2011, the company's assets were put up for auction, and purchased for $25,000 by the Wisconsin-based Space Assets LLC. The company, still steered by French, has managed to salvage what is left of the hardware—some tanks and rings—and intellectual property to develop a new business plan.[302]

Despite their termination, the engineers at Rocketplane Kistler still believed in the COTS approach to partnering with industry. Said Cuzzupoli, "I would say that the COTS program has been a very successful program, and that the whole concept of how this thing was going to be put together and housed and played out is a great idea. Cuzzupoli continued, "I think the NASA folks that are located at Johnson Space Center have done a tremendous job."[303] His colleague Brinkley added, "I'm really happy and pleased to see the success of SpaceX and the recent success of Orbital. At the end of the day, although I'm disappointed about Rocketplane Kistler and the K-1, that's secondary to the fact that COTS has been successful."[304]

Orbital Sciences Corp.

Based on the carefully established COTS strategy, in February 2008 the Commercial Crew & Cargo Program Office was able to resume plans for commercial low-Earth orbit delivery services with a new partner, Orbital Sciences Corp.

Company Founding and Early Years

David W. Thompson, Bruce W. Ferguson, and Scott L. Webster founded the Orbital Sciences Corp. in 1982, one of several aerospace companies established in the pre-*Challenger* accident atmosphere of optimism regarding the future of private space ventures. In the late 1970s, Thompson, a former engineer at the NASA Marshall Space Flight Center, had decided to pursue a business degree based on his belief that a private company could develop new systems more efficiently and cost effectively than the government.

Credit: NASA/Tom Tschida

Orbital Sciences Corp. began working with NASA and the U.S. government in the early 1980s and continued in the next decades to develop small satellites as well as the rockets to launch them. Included in NASA projects was the unpiloted X-34, a proposed low-cost reusable launch vehicle for space access. (Above) The first X-34 captive carry flight occurred June 29, 1999, using Orbital's Lockheed L-101 as the mothership, from the NASA Dryden Flight Research Center, Edwards., California. In March 2001, NASA announced it was discontinuing the X-34 program, but it served as a basis for further collaboration between NASA and the private entity.

While a student at Harvard Business School, Thompson met Ferguson and Webster, two like-minded colleagues who also shared an interest in aerospace. In April 1981—the same month as the first Space Shuttle launch—the three participated on a team that studied materials research and manufacturing in low-Earth orbit for the school's Creative Marketing Strategy course. The work was funded by the Program Development Group at Marshall, interested in potential commercial uses of Shuttle. After graduation, the former classmates stayed in contact, and on April 2, 1982, formally incorporated the Orbital Sciences Corp.[305]

Thompson described how there were almost "no precedents" in the commercial space transportation arena to look to for guidance, but two European initiatives founded in the late 1970s and early 1980s—Orbital Transport and Rockets, Inc. (OTRAG) and Arianespace—offered some proof it could be done.[306] In the era when the Shuttle was expected to provide exclusive, frequent, low-cost access to space, Orbital's initial business plan proposed to support NASA's capabilities by developing the Centaur Orbital Transfer Vehicle (OTV) that could be used to ferry payloads from the Shuttle's low-Earth orbit to the higher geosynchronous orbit required by many communications satellites.[307]

The company secured approximately $2 million from seed capital investors and venture capital sources in late 1982 and early 1983. Orbital planned to raise "most of the capital to develop and build the OTV, permitting NASA to leverage its budget with private investment and freeing space agency funds for other programs."[308] Although in this instance Congress deemed the program important enough to allocate sufficient budget for NASA to run the initiative, the statement foreshadowed the work Orbital would complete under the COTS program a quarter of a century later.

By mid-1983, Orbital began development of the Transfer Orbit Stage (TOS), a similar OTV concept designed to be a lower-cost alternative to the U.S. Air Force Inertial Upper Stage. However, the *Challenger* disaster of January 1986 forced the company to dramatically rethink its business plan to complement Shuttle activities with privately-developed systems, especially after the policy reversal of launching commercial and military satellites on Shuttle. Several of Orbital's TOS production contracts, close to completion, were delayed or cancelled. By 1988 the company had shifted focus to a second product line of small and relatively inexpensive satellites, and the expendable rockets needed to launch them.[309] As one industry observer phrased it, "the tragedy freed space enterprise from the need to move in lockstep" with NASA.[310]

Orbital based its new business plan on the company's analysis that a vehicle built expressly for the launch of small satellites could capture

this "lightsat" market by providing an alternative for small satellite customers flying their payloads as secondary cargo on the Shuttle or large-class rockets.[311] The resulting air-launched Pegasus rocket completed its first mission in 1990.

Pegasus was launched from a B-52 aircraft, a plane featured in the famous Cold War movie *Dr. Strangelove: Or, How I Learned to Stop Worrying and Love the Bomb*. Pegasus' primary architect, Antonio L. Elias, Orbital Vice President and Chief Technical Officer, later reflected on how *Dr. Strangelove* became the official film of the development team. Elias even posed for a photo on Pegasus imitating Major Kong's rodeo-style descent on the H-bomb in the film. Since then Pegasus has become a mainstay of the company's business, having conducted 45 missions as of November 2013, while also spawning numerous derivative products for space launch and missile defense applications.[312]

Throughout the 1990s, Orbital continued to expand its product line to include a variety of small satellites and launch vehicles for communications, scientific, and defense payloads. These included the Taurus and Minotaur rockets, as well as the ORBCOMM satellite communications network. Over the first two decades of operations, Orbital established a reputation as a dependable company offering NASA, military, and private industry customers reliable and cost-effective access to space.

Credit: NASA/Bill Ingalls

Lori Garver, NASA Deputy Administrator, and (left) David Thompson, CEO and President of Orbital Sciences Corporation, shared a conversation while in the Range Control Center at the NASA Wallops Flight Facility in Virginia prior to the first test flight of the Antares rocket. Also pictured are (middle) Antonio Elias, Orbital Sciences Corp. Executive Vice President and Chief Technical Officer, and Dale Nash, Executive Director, Virginia Commercial Space Flight Authority.

NASA Initiatives

NASA has been listed among Orbital's customers from the very beginning. According to Thompson, throughout the company's history NASA business has accounted for anywhere from 20 to 80 percent of Orbital's total revenue. As of 2013, Thompson reported the figure was about 40 percent, including COTS and CRS. The space agency also continues to purchase Orbital's launch services for its small scientific payloads.

Always looking for new potential business, Vice President of Human Spaceflight Systems Richard T. "Bob" Richards described how, in the early 2000s, the company anticipated a need for contingency cargo capability to ISS and developed the Orb Express concept to address potential emergency deliveries on an as-needed basis. However, NASA elected not to pursue the concept because at the time Station's needs could be fulfilled by Shuttle operations.[313]

Orbital also participated in NASA's Space Launch Initiative and Alternate Access to Station studies, and the company developed a Demonstration of Autonomous Rendezvous Technology (DART) to prove on-orbit capabilities.[314] Although none of these early initiatives reached fruition, they showed Orbital had already developed a number of ideas for cargo resupply by the time the COTS program was announced in late 2005.

COTS

Orbital was among the 21 companies that submitted proposals in response to the Round 1 COTS Announcement issued January 18, 2006. The company proposed Capabilities A and B, unpressurized and pressurized cargo delivery, but was not selected into the group of six finalists, most of which had proposed all four capabilities. (SpaceDev, Inc. was the one exception, proposing only Capabilities C and D, pressurized cargo return and the possible crew option.)

Thompson, company President and CEO, explained the decision to pursue only the first two COTS capabilities: "We concluded that returning intact cargo was not likely to be a large part of the overall traffic model, and the incremental cost of implementing that was high enough that we probably wouldn't see a good return on that incremental investment."[315] With limited potential returns on the return cargo capability, crew posed an even bigger financial risk, though an option Thompson indicated the company would be open to pursuing in the future.

Many of the engineers who worked at Orbital believed their proposal was not selected because it was overly reliant on foreign components, particularly the use of a modified Soyuz spacecraft for ISS cargo delivery.[316] After Rocketplane Kistler's Space Act Agreement was terminated in October 2007, and NASA issued the Round 2 COTS Announcement on October 22, 2007, Orbital saw another chance to be awarded a funded Space Act Agreement for the development of low-Earth orbit capabilities.

Credit: NASA/Brea Reeves

Orbital Sciences Corp. developed the Antares launch vehicle as part of its COTS Space Act Agreement. Originally named the Taurus II, the 131-foot rocket is capable of lifting over 11,000 pounds to low-Earth orbit. This medium-class vehicle reflected the company's philosophy of relying on proven hardware components.

Recognizing that COTS aimed to develop U.S.-based capabilities, the company changed its approach for the Round 2 competition. Orbital deleted the Soyuz-derived spacecraft from its proposal, but included other international elements. The company was selected, largely due to its stable finances, and signed its funded Space Act Agreement with NASA on February 19, 2008.

Vehicles

Prior to the Round 1 COTS competition in 2006, Orbital had conducted some internal studies regarding the development of a new medium-class launch vehicle. The U.S. Air Force indicated it would no longer be purchasing services on the Delta II rocket built by Boeing Integrated Defense Systems, so Orbital conceived the Taurus II, based on the company's existing Taurus small launch vehicle, as a possible replacement.[317]

Taurus II was kept in the study phase until the spring of 2007, when Orbital felt more confident about potential markets and began development work using internal funds. A ground-launched variant of the Pegasus rocket, the small-class 104-foot Taurus XL weighed 170,000 pounds and was capable of launching satellites weighing up to 3,500 pounds.[318] By contrast, the Taurus II (by then renamed Antares) that Orbital successfully launched on April 21, 2013, was 131 feet tall, weighed 530,000 pounds, and was capable of lifting over 11,000 pounds to low-Earth orbit.[319] By the time development was complete, the vehicle had been modified enough that the company felt it needed a new name to signify the substantially different vehicle that had been produced.

Not only was this medium-class vehicle appreciably larger than Orbital's previous programs, it also entailed significant design changes.

Whereas the company's other rockets utilized all solid propulsion stages, Antares was the first Orbital vehicle to use a liquid first stage. Orbital utilized a liquid first stage developed by the Ukrainian design company Yuzhnoye, manufactured by its sister company Yuzhmash. Other examples further demonstrate how Orbital's design approach leveraged proven hardware to the greatest extent possible.

Orbital purchased Aerojet AJ-26 engines to power the first stage of Antares. These units were in fact refurbished NK-33s that Aerojet had in turn purchased from Kuznetsov, the Russian company that manufactured them in the 1960s and 1970s for the failed N-1 Soviet moon rocket. (These were the same engines Rocketplane Kistler had planned to use for its K-1 system.) The second stage of Antares utilized a solid rocket motor from Alliant Techsystems, Inc. (ATK) with Orbital avionics and integration.[320]

For the cargo delivery vehicle that Taurus II/Antares would launch into low-Earth orbit, Elias proposed a flexible concept capable of supporting multiple COTS capabilities. The Service Module "hockey puck" unit contained all the necessary propulsion, power, avionics, communications, and other operational systems.[321] This could then be attached to either an Unpressurized Cargo Module (UPCM) or Pressurized Cargo Module (PCM), depending on NASA's cargo needs.

Orbital turned to an Italian company, Thales Alenia Space, to build the PCMs that would berth to Station with the aid of the robotic Canadarm. Thales Alenia was able to rely on its experience building ISS Multi-Purpose Logistics Modules, as well as the European nodes of the Station, to build this very similar module for Orbital. Another European supplier, Dutch Space B.V., was brought in to construct, test, and integrate the solar arrays for the PCM.[322]

Orbital's Round 2 COTS proposal asserted that the PCM would be capable of ferrying 2.3 metric tons (roughly 5,070 pounds) of pressurized cargo, or 2 metric tons (4,409 pounds) of unpressurized cargo to ISS. The Orbital capsule was designed to dispose of return cargo as the vehicle disintegrated upon a controlled reentry to Earth's atmosphere.[323] In keeping with the company tradition of naming vehicles based on classical Greek mythology and astronomy, Orbital named the ISS visiting vehicle Cygnus, a swan that would fly to low-Earth orbit.

Company Philosophy

The vehicles' technical capabilities reflected Orbital's philosophy of relying on an international collaboration to utilize proven hardware components. Frank DeMauro, Orbital's COTS/CRS Program Director, explained: "It's a commercial venture, we're on a fixed price, so we need to be able to do it in a cost-efficient way. We need to have very low risk, obviously from a safety point of view, but also from a raw ability standpoint."[324]

Thales Alenia Space in Turin, Italy, built the Cygnus cargo modules for Orbital Sciences Corp., relying on its experience from building the Multi-Purpose Logistics Modules for the ISS, as well as the European nodes of the International Space Station, to build this similar module for Orbital. The Italian company shipped the completed modules to the flight facility in Virginia.

Credit: Thales Alenia Space

Credit: Orbital Sciences Corp.

Team members from Orbital Sciences Corp. autographed a section of the Cygnus mass simulator which later flew atop the Antares on its inaugural flight. Many of them are pictured above with this unique "flight article" along with several NASA officials who were at the company's headquarters in Dulles, Virginia, for a milestone review. Those pictured include (center) C3PO manager Alan Lindenmoyer; and (to his left) Frank DeMauro, Orbital's COTS/CRS Program Director; Jeff Siders, Director, Houston Operations; and Frank Culbertson, Executive Vice President and General Manager of Orbital's Advanced Programs Group.

Orbital also built on the company's experience using tried and tested subcontractor components on other vehicles. Said Antares Deputy Project Director Kurt Eberly, "We tend to be in a systems integrator role," continuing, "We buy the parts, we know what the parts need to do. We do the interfaces, we do the analytical work, the simulations."[325] All of the company's rockets rely on the same basic hardware and software for functions such as guidance, navigation, and control, which the company is then able to adapt to new configurations based on customer need. According to Michael R. "Mike" Pinkston, Senior Vice President for Antares, "I don't think there's any substitute for building that kind of historical, heritage-based understanding of what you're applying," adding, "It's simply adapting, and that's really how we've done business for years."[326]

Orbital engineers and officials described how they always endeavored to pursue a policy of openness regarding the COTS development process, with both NASA and the public. This included a candid explanation of mission successes as well as failures. Frank L. Culbertson, former Space Shuttle astronaut and Executive Vice President and General Manager of Orbital's Advanced Programs Group, described how after a press conference, members of the media approached him and expressed their gratitude for the company's "quiet competence."[327] An already

established company with over three decades of experience, the company hosts press conferences for its major launch events.

NASA Partnership

Although the company used a different approach to develop its vehicles than SpaceX and Rocketplane Kistler, NASA's Commercial Crew & Cargo Program Office still worked with Orbital as a partner, not a supervisor. Culbertson echoed Project Executive Bruce A. Manners' statement that NASA had to allow the company to develop the vehicles based on what would be best for their future customers, not just for the space agency. A former NASA Program Manager, Culbertson said he appreciated the suggestions, but, "it's our design, and we'll make our own decisions … [to] decide what's the safest, most efficient, and cost-effective approach."[328]

Orbital did value NASA's advice and expertise from both the Project Executive and the COTS Advisory Teams. As Jeffrey A. Siders, Orbital Director of Houston Operations explained at the 4th SpaceUp Houston conference on February 8, 2013, "NASA brings in the lessons learned, they ensure we're doing things safely, they help us in design decisions—although the final decision is left to us."[329]

Milestones

As with the other two commercial partners, Orbital's Space Act Agreement with NASA outlined a series of predefined milestones to track the development of the company's low-Earth orbit transportation system.

Credit: Orbital Sciences Corp.

Orbital Sciences Corp. integration and test engineers performed final test and check-out activities for the first two Cygnus Service Modules at the company's Satellite Manufacturing Facility in Dulles, Virginia. Multiple service modules can and are being assembled and tested in parallel to support COTS and the follow-on Commercial Resupply Services missions. A full-scale poster of a fully assembled Cygnus on the wall illustrates the overall size of the spacecraft once on orbit.

Financial Milestones

Because of Orbital's ability to use existing internal funds to pay for COTS development, the company's SAA did not include any financial milestones.

However, all the COTS partners struggled to raise the financial capital necessary to develop their products at some point, and Orbital was no exception—especially in the early years of the company. According to Thompson, "That was probably the biggest single problem that we had to solve," as Orbital "used just about every form of financing that was available during the '80s and '90s"—from private investment, to venture capital, to debt financing, to research and development limited partnerships—to get the new startup off the ground.[330] After maximizing the

Credit: Orbital Sciences Corp.

Interface inspections between the Antares rocket and the Antares launch mount were conducted by Orbital Sciences Corp. after the rocket had been transferred to the launch pad using the Transporter, Erector, Launcher (TEL).

amount of funding available from private sources, in 1990 Orbital went public with an IPO, "the equivalent of high school graduation for a rapidly growing enterprise."[331] This initial offering was followed by a series of further public stock offerings and debt financings in the 1990s.

By the early 2000s—roughly 20 years after the company was founded—Orbital finally reached a position of stability where the company no longer needed to raise additional capital; profits from its existing rocket and satellites programs were sufficient to maintain the company's operations. Orbital put a significant amount of its own internal funds at risk, about $590 million over the five-year course of the COTS agreement, in order to develop the company's low-Earth orbit transportation capabilities. Orbital operated the program at a financial loss prior to the COTS demonstration flight, hoping its initial investment would be recuperated once the system became operational.[332]

Technical Milestones

As with SpaceX, some negotiations took place regarding the originally planned technical milestones, again showcasing the space agency's flexibility in adapting to the commercial partners' needs—not the other way around. When Orbital signed its Space Act Agreement with NASA in February 2008, the company proposed to complete its demonstration flight using an Unpressurized Cargo Module. However, in December 2008 the ISS Program Office awarded Orbital a $1.9 billion Commercial Resupply Services contract for eight flights of pressurized cargo only.

Seeing that it would not need to supply any unpressurized cargo to the ISS in the foreseeable future, Orbital requested that its UPCM demonstration mission in the Space Act Agreement be replaced by a demonstration mission utilizing the Pressurized Cargo Module instead. NASA agreed to the change, and amended the Orbital SAA milestones to reflect the new plan.[333]

Another prominent example of flexibility and negotiation occurred regarding the "Launch Vehicle Stage 1 Assembly Complete" milestone. Although the definition would seem fairly straightforward, the milestone became the topic of significant discussions between C3PO and its commercial partner. As Orbital's manufacturing process evolved over the course of development, the order of the rocket build changed from the original plan established at the time the SAA was signed. Parts of the second stage were now attached before the first stage was fully assembled. Project Executive Bruce Manners explained the quandary: "Well, do I pay them early? … Does it make sense for me to have them take that second stage off, put the first stage pieces on there, and take it back off so they can attach the first?"[334]

By using an overhead crane, Orbital's integration and test engineers lifted one of the three main propellant tanks into the structure of the Cygnus Service Module. This Service Module was flown on the COTS Demonstration Mission that was successfully completed in October 2013.

Credit: Orbital Sciences Corp.

In the end, the partners agreed to a "physical configuration audit" in which NASA representatives conducted an in-person examination of the partially assembled first and second stages, and approved Orbital's documentation showing the remaining first-stage parts were accounted for and ready to be added to the existing architecture.[335] In addition to these matters of negotiation, Orbital faced two primary technical hurdles in the course of its Space Act Agreement with NASA, discussed below.

AJ-26 Engines

The AJ-26 engines used to power the Antares first stage—part of Orbital's strategy to use already available, proven hardware—proved more cantankerous than the company had originally anticipated. Early development tests at NASA Stennis Space Center revealed that after sitting in storage for 35-plus years, some of the engine components had succumbed to stress corrosion that resulted in a split fuel manifold line. (This testing was conducted under the terms of a separate, reimbursable Space Act Agreement with Stennis Space Center, in which Orbital paid NASA for the use of its specialized testing facilities which were not available from a commercial provider.)[336]

In order to address the problem, Orbital relied on the COTS Advisory Team, materials and corrosion experts brought in by the Commercial Crew & Cargo Program Office to help with specific problems. Together, Aerojet and Orbital developed a "nondestructive evaluation program" of X-rays and eddy current inspections to detect cracks and repair them by welding if necessary.[337] In addition to the stress corrosion issue, a CAT member at NASA White Sands Test Facility also provided data that helped prevent particle contamination of the liquid oxygen that could result in accidental ignition.[338]

Mid-Atlantic Regional Spaceport

The second major obstacle for Orbital in the development of its commercial orbital transportation system was the development of the Mid-Atlantic Regional Spaceport (MARS) launch site adjacent to the NASA Wallops Flight Facility on the eastern coast of Virginia. In 1995 the Commonwealth of Virginia created the Virginia Commercial Spaceflight Authority (VCSFA). After leasing a tract of land from NASA and acquiring the necessary license from the Federal Aviation Administration Office of Commercial Space Transportation, MARS was established in 1997 for the launch of small launch vehicles from Pad 0B, including Orbital's Minotaur rocket.[339]

Orbital elected to conduct its Antares launches at MARS after reviewing proposals from both MARS and Space Florida, which proposed to host the company's launches from Cape Canaveral. Factors in favor of MARS included its proximity to Orbital's headquarters in Dulles, Virginia; Orbital's familiarity with the Wallops site and organizational culture; and the political support of Maryland Senator Barbara A. Mikulski. Furthermore, the VCSFA promised to fund MARS directly through the use of tax-free bonds, whereas Space Florida would need to seek financing through investors and loans.[340] Orbital determined these positives outweighed some of the advantages offered by Space Florida, in particular Cape Canaveral's well-developed existing launch infrastructure for medium- and large-class rockets.[341]

Credit: NASA/Wallops

Maryland Senator Barbara Mikulski (center) cut the ribbon March 22, 2011, to open the Horizontal Integration Facility at NASA's Wallops Flight Facility. Built to support medium-class launch vehicles, Orbital Sciences Corp. was the first customer to use the facility for its Antares vehicle. On hand for the event were (left to right), Bill Gerstenmaier, NASA Associate Administrator, NASA Administrator Charlie Bolden; and David Thompson, CEO and President of Orbital Sciences Corporation.

In September 2008, the old Pad 0A was razed in order to begin construction on the infrastructure required for Antares. The process of developing MARS Pad 0A for a medium-class rocket, starting "from a green field," was more expensive and more time consuming than either MARS or Orbital had foreseen.[342] The liquid fuel farm that supplies

Credit: NASA/Bill Ingalls

The Mid-Atlantic Regional Spaceport, a commercial space launch facility, is located on Virginia's Eastern Shore. Orbital Sciences Corp., NASA, state, and local officials coordinated efforts to transform Pad-0A into a facility that could support the medium-class Antares rocket.

propellant to the rocket presented an especially troublesome area, as operations required a complex and precise configuration of components to ensure correct cleanliness levels, temperatures, pressures, and flow rates. Specific issues included "bad welds, valves that didn't work, [and] resonances in the fueling system that caused it not to operate."[343]

Thompson reported that the cost was about three times higher and the site took two years longer to complete than originally estimated. Complicating matters was the complex nature of relationships between federal and state agencies and the private corporation, as NASA, VCSFA, and Orbital coordinated to prepare the facility for launch. To help relieve the issue, NASA contributed the horizontal vehicle assembly building, and Orbital advanced about $45 million to the state of Virginia in order to complete development. The accumulation of small issues resulted in what turned out to be lengthy delays, but work was finally completed in October 2012.[344]

Augmentation Milestones

Orbital received an additional $118 million as a result of the fiscal year 2011 augmentation of the COTS budget, and NASA and the company agreed to 10 additional milestones to accelerate development and mitigate risks.

These additional SAA milestones were divided into three main tasks: the addition of a Taurus II (Antares) maiden flight, installation of an additional processor-in-the-loop simulator, and a Proximity Flight Equivalent Unit (PROX FEU) test

unit for ISS integration testing.[345] The latter two items provided additional software to improve the accuracy of modeling and operations, but for both NASA and Orbital the most important milestone was the additional test of the launch vehicle.

The addition of a test of the rocket prior to attempting a launch of the entire system allowed Orbital to verify that this crucial element could complete its role in the mission before attempting the full journey to ISS. According to Orbital officials, this test was one the company had wanted to complete at the beginning of the program, but the available NASA and internal funding did not allow for its inclusion in the original Space Act Agreement.[346]

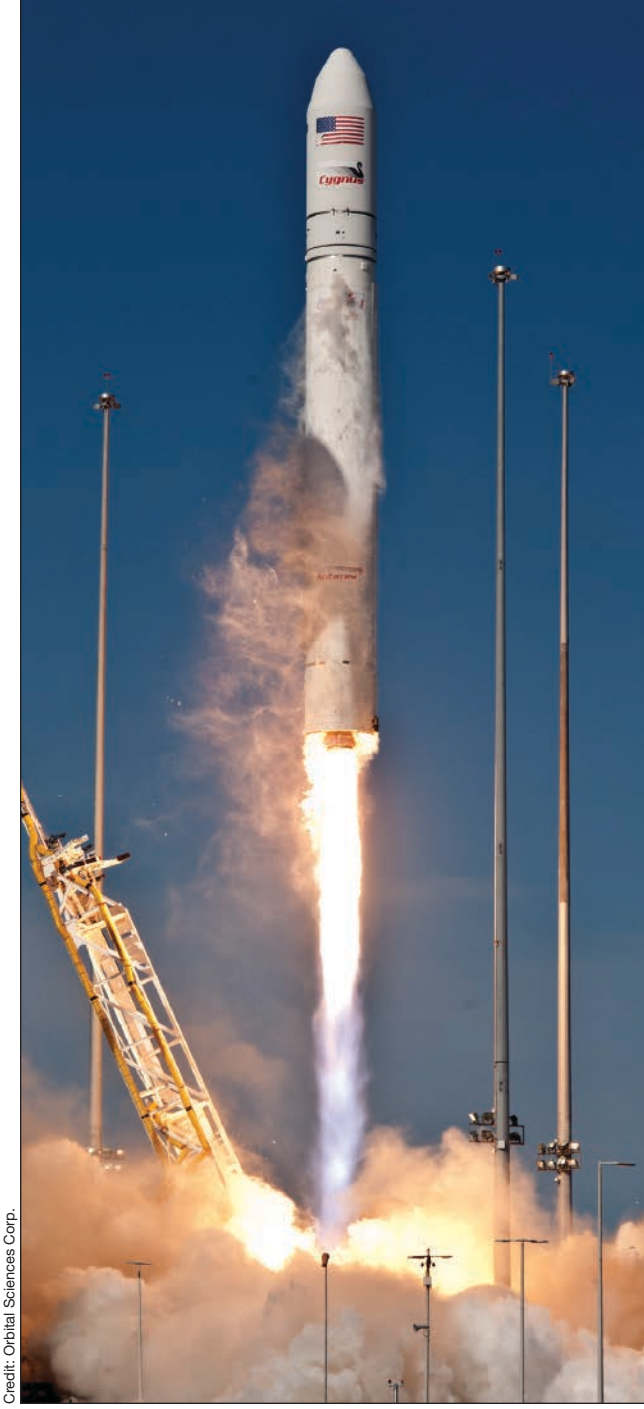
The Antares test flight launched a Cygnus mass simulator, designed with the same weight, volume, and center of gravity as the PCM that would later be launched to ISS. Eberly explained, "The rocket launch is the most astringent environment that a spacecraft will see in its lifetime," so adding thermometers, microphones, and other instrumentation to measure factors such as vibration, acoustic, and thermal loads helped collect information to ensure Cygnus would be able to handle the launch environment in order to successfully complete the ISS demonstration mission.[347]

Antares Test Flight

On February 22, 2013, Orbital completed a successful hot fire test of the Antares rocket on MARS Pad 0A, and two months later the company's perseverance and commitment to resolving issues culminated in what was described as a "flawless" and "perfect" test flight of the rocket. After two scrubs, the first due to a disconnected data cable and the second due to high winds, Antares successfully launched from Pad 0A at 5:00 p.m. local time on April 21, 2013. The separation of the first and second stages of the rocket occurred exactly as planned, and 10 minutes after launch the Cygnus mass simulator was deployed and reached close to its targeted orbit of approximately 150 to 160 miles. The inclination of 51.6 degrees matched that of ISS and the company's upcoming final demonstration mission.[348]

Describing the tension in the control room at Wallops, DeMauro said, "I don't recall ever being as nervous as I was—not because I didn't think it would work, just because all of us knew how important it was."[349] Eberly, who had worked on the rocket since its inception as Taurus II in April 2007, added, "We'd done our homework, but you can never be sure that everything's going to work properly together."[350] When the moment of first-stage separation arrived, the control room erupted in spontaneous applause, the managers and engineers relieved and elated to see all their hard work culminate in a successful mission, "all feeling like little kids again, feeling completely renewed."[351]

In addition to the Cygnus mass simulator, Antares also deployed three experimental PhoneSats—called Alexander, Graham, and Bell—that used smartphones to photograph the Earth from space. Other picosatellites, including the Dove-1 satellite dedicated to amateur radio, provided additional data for those interested in "open[ing] space to a whole new generation of commercial, academic, and citizen-space users."[352]



Credit: Orbital Sciences Corp.

The Antares rocket launched from Pad-0A of the Mid-Atlantic Regional Spaceport on the NASA Wallops Flight Facility in Virginia on April 21, 2013. The test launch marked the inaugural flight of the Orbital Sciences Corp. rocket and the biggest rocket ever launched from this facility. The Antares deployed a Cygnus mass simulator and three experimental PhoneSats—Alexander, Graham, and Bell—that used smartphones to photograph the Earth from space.

Cygnus Demo Mission

On September 18, 2013, Orbital conducted its second launch of the Antares rocket, this time aiming for the International Space Station with a fully-operational Cygnus as its payload. The company named the spacecraft for G. David Low in honor of the three-time Space Shuttle astronaut and former Orbital executive who had passed away in March 2008.[353]

Ten minutes after launch, at 11:08 Eastern time, the Cygnus capsule separated from the second stage of Antares and began its journey to low-Earth orbit.[354] Cygnus successfully performed its first on-orbit tasks, for example deployment of its solar arrays and an abort demonstration. However, approximately six hours before it was due to berth with ISS on the morning of September 22, Orbital and NASA engineers discovered a discrepancy in the navigation software used by Cygnus and ISS.

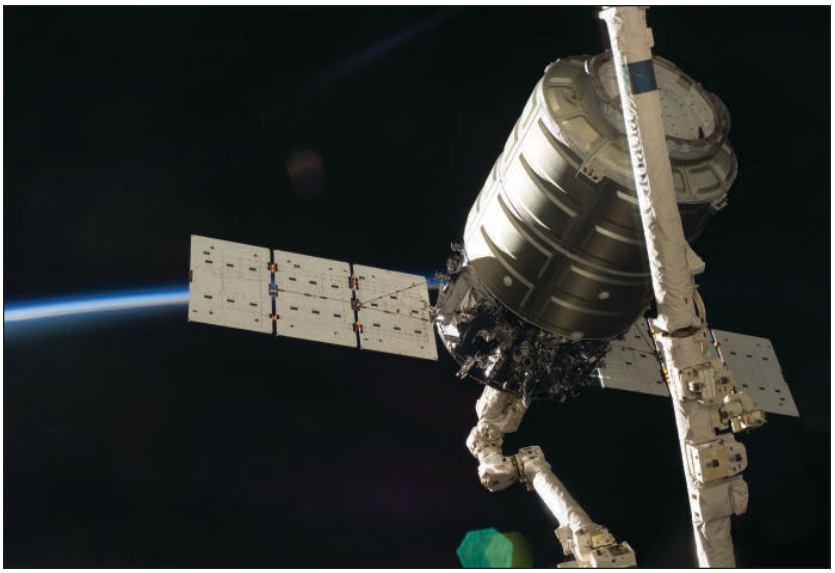
Credit: NASA/Bill Ingalls

NASA Administrator Charles Bolden (right) congratulated the Orbital Sciences Corp. launch team and management in the Range Control Center at the NASA Wallops Flight Facility after the successful maiden launch of the company's Antares rocket.

The team decided the most prudent course of action would be to delay the berthing by one week. This would allow sufficient time for the team to upload a software fix, and for three new Expedition 38 crew members to arrive via the Russian Soyuz on September 25.

Eleven days after the Antares launch, in the early hours of the morning on Sunday, September 29, 2013, Cygnus began its approach toward the Earth-facing, or nadir, side of the International Space Station. After demonstrating its remaining on-orbit tasks, including

NASA astronaut Karen Nyberg (left) and European Space Agency astronaut Luca Parmitano, both ISS Expedition 37 flight engineers, monitored the approaching Cygnus spacecraft as it neared the ISS, on September 29, 2013.



About 10 meters away, the ISS crew members used the Canadarm2 to grapple the Orbital Sciences Corp. cargo module. The Cygnus remained at the ISS for three weeks before it was released with disposables from the International Space Station. As planned the Cygnus spacecraft destructively reentered the Earth's atmosphere over the Pacific Ocean.

retreat and hold capabilities, at 5:00 a.m. local time NASA Mission Control in Houston granted the capsule permission to enter the Station's 660-foot Keep Out Sphere.

The grapple that was planned for 11:15 a.m. GMT occurred slightly ahead of schedule, as American astronaut Karen Nyberg and Italian astronaut Luca Parmitano operated the Station's robotic Canadarm for a successful grapple of the "beautiful baby swan" at 11:02 a.m. GMT, as ISS passed over the Indian Ocean.[355] Afterward, C3PO Manager Lindenmoyer described the mission as "just beautiful," as he praised Orbital for its "professional, skilled" approach to addressing development and mission challenges "with such expertise over the years."[356]

The next day, the astronauts and cosmonauts onboard the ISS began unloading the vehicle's 1,543 pounds of cargo. On October 23, 2013, Cygnus completed its three-week stay by deorbiting from ISS, this time loaded with disposables from the Station, and destructively reentering Earth's atmosphere over the Pacific Ocean.

Ready for the Future

In the course of Orbital's Antares and Cygnus development programs, the company's demonstration flight to ISS occurred after a cumulative delay of almost three years, as the terms of the original Space Act Agreement planned for the ISS demonstration mission to occur in December 2010. Many of these delays were the result of launch pad development issues outside of Orbital's control, and members of C3PO expected at least some degree of schedule slips based on the partners' original, aggressive schedules. In the words of Orbital Project Executive Bruce Manners, "They make jokes about rocket science for a reason."[357] However, having cleared the hurdle of the demonstration mission, Orbital was now ready to commence regular resupply missions under its $1.9 billion Commercial Resupply Services contract.[358] Culbertson discussed how future missions would be capable of carrying more cargo, over two and a half tons (5,000 pounds) by the fourth CRS mission, and focus more on scientific payloads for ISS research. Because future missions would not have to complete on-orbit demonstration tasks, these payloads could arrive at ISS within two to three days after launch.

Credit: C3PO team

NASA's commitment to work with commercial partners extends into the future. Among those from the space agency who continue to support this effort are (left to right) Marc Timm, COTS Program Executive, NASA Headquarters; Phil McAlister, NASA Director of Commercial Spaceflight Development; Dennis Stone, C3PO Program Integration Manager; and Sam Scimemi, Director for International Space Station at NASA Headquarters.

Credit: NASA/James Blair

Frank Culbertson, (center), Executive Vice President and General Manager of Orbital's Advanced Programs Group, provided details about the Cygnus demonstration mission at a press conference held at JSC. Seated next to him was C3PO Manager Alan Lindenmoyer, and ISS Flight Director Courtenay McMillan (right), who during the mission gave the go-ahead for the Cygnus to rendezvous and berth with the International Space Station.

Credit: NASA/Jay Westcott

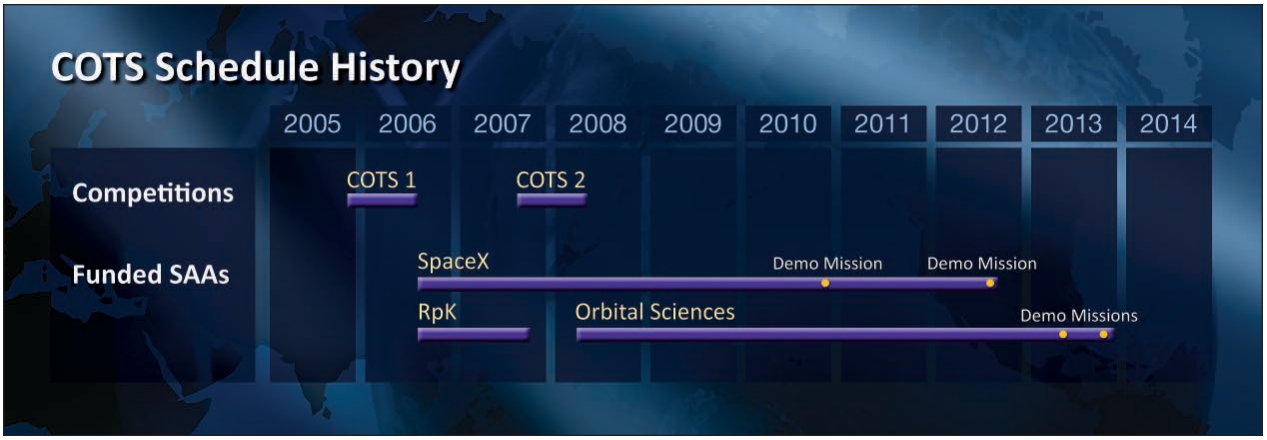
NASA Administrator Charlie Bolden recognized the Commercial Orbital Transportation Services program and its commercial partners for innovative accomplishments and outstanding contributions to the space agency. (Pictured left to right) Bolden presented the NASA Group Achievement Award to Frank Culbertson, Executive Vice President and General Manager, Orbital Sciences Corp. Advanced Programs Group; Gwynne Shotwell, President, SpaceX; and Alan Lindenmoyer, Manager of NASA's Commercial Crew & Cargo Program. Bolden stated how "America's best days in space exploration are ahead of us" during the awards ceremony held at NASA Headquarters in Washington, DC, November 13, 2013.

Culbertson explained, "We're happy to take food and clothing…but we want to make sure that we're also able to provide the science and the research that can be accomplished on the Station," adding, "We know and understand and accept the responsibility that this is critical to the continuation of the Station and the continuation of U.S. leadership in space."[359]

Several observers have pointed out how a relatively small government investment has resulted in the development of a new low-Earth orbit delivery system—comprised of a medium-class launch vehicle, the Cygnus capsule, as well as the ground-support technologies and infrastructure that allow those vehicles to function—for both government and private-sector customers. From the time Orbital and NASA signed the Space Act Agreement in February 2008 through June 2013, NASA contributed approximately $288 million in milestone funding for the COTS development work, while Orbital spent a total of approximately $590 million, contributing more than twice the NASA commitment to complete the program.

Orbital has more than three decades of experience with small launch vehicles and satellites, although it started off focusing on a single NASA program. Over time (especially after the *Challenger* accident in 1986) the company continued to grow and diversify, moving from small temporary facilities to a larger campus on Warp Drive in Dulles, Virginia in 1993.[360]

If Rocketplane Kistler provides the example of an unsuccessful aerospace startup, and SpaceX a fledgling company in rapid growth, Orbital shows one possibility for what a mature aerospace company can look like after 30 years of operation. Now both COTS commercial partners had the opportunity to finish a project conceived decades ago—private cargo resupply services to support NASA's mission in low-Earth orbit.



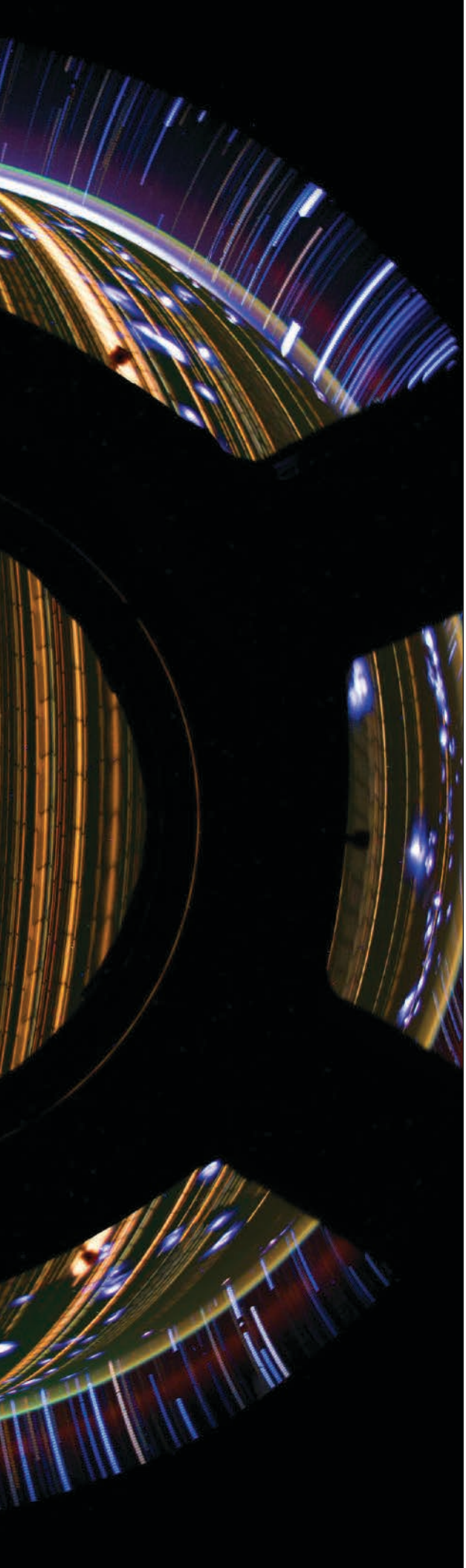
This timeline illustrates the eight-year history of the COTS program, beginning with the first competition in 2006 and culminating with the final partner demonstration missions in 2013.

Collaboration

International Space Station

Federal Aviation Administration

Chapter 6



Unique in its operations, the Commercial Crew & Cargo Program Office (C3PO) worked with organizations within NASA, as well as other federal agencies, to stimulate the commercial space industry. Interactions with the International Space Station (ISS) Program Office and the Federal Aviation Administration (FAA) Office of Commercial Space Transportation proved that while COTS forged new relationships between NASA and industry, the program's innovative methods could mesh with established tradition. Although not everyone accepted this new approach at the outset, the achievements of the Commercial Orbital Transportation Services (COTS) initiative remain evident, and lessons learned from the program continue to be utilized.

International Space Station

As a multi-billion dollar asset, the International Space Station maintains a strict set of requirements for vehicles approaching within 660 feet of its football field-sized structure, the so-called Keep Out Sphere (KOS), to protect the Station's structure, equipment, scientific experiments, and human crew. Potential issues for commercial cargo missions included vehicle collisions, micrometeoroid strikes, and plume impingement, i.e., visiting vehicle exhaust streams that could leave harmful deposits of contaminants and/or damage delicate structural elements of the Station such as solar arrays.[361]

Under the COTS program, the Space Exploration Technologies Corp. (SpaceX), Orbital Sciences Corp., and Rocketplane Kistler (RpK) all proposed to perform the demonstration of their low-Earth orbit capabilities by visiting the ISS, and therefore were required to meet the Station's visiting vehicle requirements. COTS offered the possibility of a U.S.-based option for not only carrying additional cargo, including powered payloads for science experiments, but also returning research samples back to Earth for study.

The ISS Transportation Integration Office (TIO) already had experience collaborating with external organizations through its work integrating International Partner resupply vehicles to the Station's modules.

Before the development of U.S. commercial cargo capabilities, the ISS relied on four international vehicles (in addition to the Space Shuttle) to provide regular resupply services: the Russian Federal Space Agency's Soyuz and Progress spacecraft, the European Space Agency's Automated Transfer Vehicle (ATV), and the Japan Aerospace Exploration Agency's H-II Transfer Vehicle (HTV).[362] The Soyuz transports up to three people to and from the ISS, but the Progress, ATV, and HTV can carry cargo only. Upon reentry into Earth's atmosphere, these cargo vehicles disintegrate and incinerate waste materials returned from ISS.

The International Partner experience laid the groundwork for the COTS visiting vehicles, as NASA personnel learned from working with their Russian, European, and Japanese counterparts the need to minimize and clearly communicate even seemingly basic aspects of the launch, rendezvous, and docking process (including standard NASA procedures such as the Certification of Flight Readiness).

Credit: NASA/Bill Ingalls

While the commercial partners developed their launch vehicles and cargo delivery systems, the ISS Transportation Integration Office worked closely with the companies to ensure a safe transport to and from the orbiting laboratory. NASA's ability to conduct new scientific investigations for the ISS Program, led by Manager Mike Suffredini (above), significantly increased because of the rockets and spacecraft built by SpaceX and Orbital Sciences Corp. The ISS Program was extended until at least 2024 by President Barack Obama. In the near-term, all current and planned U.S. experiments aboard the International Space Station will be facilitated in some way by a SpaceX or Orbital Sciences Corp. resupply mission.

This helped ensure all the International Partners were, as it were, speaking the same language.[363]

TIO Manager Kathryn L. Lueders was assigned the role of COTS-ISS integration in October 2006, roughly two months after the Round 1 Space Act Agreements were signed. She became responsible for tailoring the visiting vehicle requirements for commercial vehicles. To meet the early December deadline for the first SpaceX System Requirements Review, Lueders relied on the draft COTS ISS Interface Requirements Document that had been developed as a guide by C3PO Deputy Program Manager Valin B. Thorn, using it as a starting off point to negotiate in tandem with the selected COTS companies.[364]

Lueders emphasized that she "viewed the companies as a partner," working with them collaboratively to determine how both parties could meet their respective needs.[365] For the COTS industry partners, this meant developing their vehicles as expeditiously as possible, without being hampered by superfluous requirements that did not reduce the risk of operations. For the ISS Program Office, this meant ensuring the safety of the Station and its inhabitants.

ISS TIO met with representatives from each of the COTS partners to negotiate their visiting vehicle requirements (including RpK before its Space Act Agreement with NASA was terminated in October 2007). The companies were allowed the opportunity to question the rationale behind each of the many requirements for ISS docking and berthing. These questions forced the ISS Program Office to consider the justification for each of the technical obligations imposed, ensuring the requirements truly contributed to mission safety, instead of maintaining a set list out of tradition. Frank DeMauro, Orbital's COTS/CRS Program Director, referred to the discussions as collaborations: "It's important to point out that it wasn't stake-in-the-ground, no flexibility."[366]

These negotiations also allowed Station engineers to impart some of their wisdom and lessons learned to the partners. For example, Orbital was able to simplify its avionics system as a result of working with the ISS Program Office.[367] In fact, for both Orbital and

Credit: NASA/Kim Shiflett

Under the COTS program, the government and private sector invested funds, shared risks, and moved through technical challenges to successfully restore U.S. cargo transport capabilities for the ISS. Alan Lindenmoyer, Manager of NASA's Commercial Crew & Cargo Program, described COTS as "a new era in spaceflight." He is pictured above with Gwynne Shotwell, President of SpaceX, the first commercial partner to complete its COTS milestones.

SpaceX, software compatibility proved to be a formidable issue. SpaceX also experienced issues because it utilized a more recently developed programming language, rather than those used by NASA's heritage systems.[368]

In some cases the NASA project executives served as brokers between the partners and their counterparts in the ISS Program Office. Michael J. "Mike" Horkachuck, Project Executive for SpaceX, described how he was able to apply his knowledge of ISS development history to "influence how hard the ISS team was pulling on a particular requirement, and try to add a little bit of sanity to meeting the letter of the law versus the overall intent."[369] Horkachuck explained that he was able to "talk to the NASA side, whoever was raising the concern, and understand, mediate our way through."[370]

In addition to the requirements, NASA and its commercial partners also negotiated how to verify that those requirements had been met. That is, to use an example from SpaceX, what kind of data was required to show that the Dragon spacecraft's software was compatible with ISS avionics. According to SpaceX President Gwynne E. Shotwell, the verification process was a huge challenge that was sometimes "painful for both NASA and SpaceX," because "there are hundreds, if not a thousand or so, requirements." She added that there were years of discussion on, "how do you prove that you've met them?"[371]

However, in the end, SpaceX employees reflected that they had "an opportunity to grow together with the ISS office" during COTS and developed a harmonious working relationship with NASA.[372]

Orbital Vice President Antonio L. Elias described the interaction as one "of two organizations: one that knew a lot about commercial low-cost space, the other that knew a lot about traditional government procurement and tests, and both trying to find a way to do things in a satisfactory way."[373]

The ISS Program Office also adapted to allow commercial partners to retain their intellectual property rights as specified under the terms of their COTS Space Act Agreements. TIO learned how to work with companies' proprietary data from both the COTS program and the NASA Launch Services Program (LSP) at the Kennedy Space Center, another group that was accustomed to buying services and having limited rights to this type of information. Conversely, the commercial partners learned how to better compartmentalize their documentation, separating company technical design data from documents needed for ISS integration. This was especially important because some COTS partner integration data was not only shared with NASA, but also NASA's International Partners.[374]

SSP 50808

In the summer of 2007, the ISS Program Office produced Space Station Program (SSP) 50808, the ISS to COTS Interface Requirements Document. ISS Program Manager Michael T. Suffredini determined that SSP 50808 would be the only volume private entities would need in order to visit ISS, as opposed to producing individually-tailored books for each partner. One integrated volume "really makes the Station Program have to justify why that requirement is there, and why it's worded a certain way," explained Lueders.[375]

Like COTS, SSP 50808 reflected NASA's new way of doing business. The document continued to evolve as NASA added to the number of private enterprises aiming to visit the International Space Station, including the companies that participated in NASA's follow-on commercial crew programs. For example, Revision D, the updated version of SSP 50808 released in early 2012, added specifications for docking directly to the Station, whereas previous versions had only addressed berthing to ISS with the aid of the robotic Canadarm. A continued effort was made to make the volume easier for new commercial providers to use and understand.

Commercial Resupply Services Contracts

The original plan for NASA's commercial initiative called for its execution to occur in two consecutive phases. In Phase 1, COTS, the commercial partners would develop and demonstrate their low-Earth orbit transportation systems. Understanding that COTS would create viable competitors for a follow-on procurement, Phase 2 would then entail the purchase of these fully-developed services through a traditional Federal Acquisition Regulation-based services contract. This Commercial Resupply Services (CRS) contract was issued by the ISS Program Office, the customer of those services, independently of C3PO.

In December 2008 NASA awarded Commercial Resupply Services (CRS) contracts to both COTS partners. SpaceX was contracted for 12 missions and launched its first CRS flight on October 7, 2012. Shown below is the Falcon 9 rocket with the Dragon spacecraft on board prior to the second delivery, SpaceX CRS-2, that lifted off March 1, 2013.

Credit: NASA/Tony Gray and Robert Murray

NASA originally planned to compete and award CRS after the participating COTS companies had successfully completed all the milestones of their Space Act Agreements and proven their ability to deliver cargo to a destination in low-Earth orbit. But, in the spring of 2007 a NASA team composed of Lindenmoyer, Lueders, and Ramon Lugo, Deputy LSP Manager, concluded that awarding CRS after the COTS missions could adversely impact Station.

Based on the original schedule for the commercial partners' demonstration missions, and with the anticipated retirement of the Shuttle looming, if NASA waited until those demonstration missions were complete, the Station would face a 27- to 30-month servicing gap due to the lead time required to start a new contract. This could mean a cargo shortfall of 48.8 metric tons (107,585 pounds) or more. Plus, if development delays occurred within the COTS program, the gap could increase even more. Therefore, the team recommended that the procurement for CRS take place much sooner than originally planned.[376]

According to the team's analysis, the contract needed to be awarded by December 2008 at the latest. On August 7, 2007, the Space Operations Mission Directorate (SOMD) at NASA Headquarters issued a Request for Information, soliciting input from commercial companies on their potential to provide commercial cargo services to ISS.[377] After three days of meetings with industry, NASA determined that sufficient interest existed in order to release a Request for Proposals for a commercial

resupply contract. The CRS Request for Proposals was issued on April 14, 2008, and ISS awarded the CRS contract on December 23, 2008—only a few months after the first successful flight of the SpaceX Falcon 1 rocket, and less than a year after Orbital signed its SAA with NASA.[378]

William H. "Bill" Gerstenmaier, head of the Space Operations Mission Directorate (SOMD) in 2008 at NASA Headquarters, later explained that "if we didn't move out with some kind of services contract there was going to be no ability to resupply the Space Station. This is where it became serious. We absolutely needed this service; we were destined to retire the Shuttle." He added, "We had no choice. If we were going to deliver, we needed to go do the services contract, move out, and move forward." Gerstenmaier reemphasized that "I didn't want to do this procurement [before the capabilities were demonstrated], but I had to because of the time criticality."[379]

Unlike the COTS Space Act Agreements, CRS was a procurement; NASA was buying a definite service, with a contract subject to the Federal Acquisition Regulations. A different set of personnel participated in the Source Evaluation Board and procurement process than were involved in the contemporaneous COTS work. NASA Deputy General Counsel Sumara Thompson-King explained, "People, language, resources—we put up a firewall of sorts to make sure that, as much as we could within the Agency and external to the Agency, they were viewed as different processes."[380]

Gerstenmaier served as the CRS selection official, making the ultimate decision regarding which of the three companies that submitted proposals would receive the award. In the end Gerstenmaier decided to select two companies, in order to allow for redundancy to ensure the Station received all 40 metric tons (88,185 pounds) of supplies needed by the end of the contract.[381] As with the first round of the COTS competition, SpaceX submitted the most highly ranked proposal, receiving the highest score for both the evaluation criteria of 1) mission suitability, and 2) lowest price (with the former prioritized as more important than the latter).[382]

Although the Source Evaluation Board scored PlanetSpace marginally higher than Orbital Sciences Corp. for both criteria, Gerstenmaier found that several weaknesses in the PlanetSpace proposal outweighed its potential strengths. First, although PlanetSpace's subcontractors Lockheed Martin Corp., The Boeing Company, and Alliant Techsystems, Inc. (ATK) had substantial past experience working on government programs, the same could not be said of PlanetSpace itself. Second, NASA found multiple issues with the company's cost assumptions. For example, PlanetSpace would be awarded a fixed-price contract from NASA, but planned to pay its subcontractors on a cost-plus basis—resulting in a potentially significant financing gap which the company had no reasonable plan to address. NASA also found several of the company's technical, schedule, and costs assumptions to be "unrealistically optimistic."[383]

NASA's Source Evaluation Board noted Orbital's use of Aerojet AJ-26 engines—refurbished decades-old Russian NK-33s originally developed for the Soviet Moon program—as a weakness. This weakness was not ranked as significant because it was somewhat mitigated by subcontractor

Credit: NASA/Paul E. Alers

William H. "Bill" Gerstenmaier, as NASA Associate Administrator for the Human Exploration and Operations Directorate, provided updates to Congress on both the COTS and CRS programs. He included details of the progress as well as explanations of what he called the "challenges associated with a technologically ambitious endeavor." Gerstenmaier began his career with NASA in 1977 and through the years led major efforts for the space agency including the Space Shuttle and International Space Station programs prior to 2005 when NASA named him to lead the agency's Space Operations Mission Directorate. In 2012 Gerstenmaier's duties expanded with his current role.

Credit: NASA/Bill Ingalls

NASA contracted with Orbital Sciences Corp. to complete eight missions to the ISS as part the Commercial Resupply Services (CRS) contract. The Antares rocket (shown above) with the Cygnus cargo capsule filled with crew provisions, spare parts, science experiments, and other hardware launched on January 9, 2014, for its CRS-1 mission.

Aerojet's experience and the fact that the engines were stored in a humidity-controlled environment. On the whole, NASA found that this weakness was balanced by the strengths of Orbital's existing processes and in-house expertise. Orbital also proposed to deliver ISS resupply services by 2012, a year earlier than PlanetSpace.[384]

The fixed price Commercial Resupply Services contracts were thus awarded to the two COTS partners, SpaceX and Orbital. Each of the respective contracts began on January 1, 2009, and ran through the end of 2016, requiring delivery of 20 metric tons (about 44,100 pounds) to the International Space Station, distributed over multiple flights. SpaceX was contracted to deliver the specified quantity of upmass (cargo to ISS) over 12 missions for a total price of $1.6 billion. Orbital was contracted for eight missions for a total of $1.9 billion.[385]

Government Accountability Office Protest

After losing to SpaceX and Orbital, PlanetSpace protested NASA's decision at the Government Accountability Office (GAO), where, as with the two protests of the COTS awards, the NASA legal teams at JSC and NASA Headquarters again successfully defended the space agency's selection. The GAO issued its decision on April 22, 2009, explaining that despite PlanetSpace's claims of biased treatment, the selection process had been fair and transparent.[386]

For many on the legal team, the protest itself was less significant than NASA's decision to override the "automatic stay" provision that requires the Agency to put the program on hold for 100 days while the GAO makes its decision. Because ISS resupply services were seen as increasingly critical to the Agency's mission to maintain the International Space Station, Gerstenmaier made the risky decision to override so that the CRS contract could be implemented as quickly as possible. Gerstenmaier spent hours on the stand justifying his decision, and as another credit to the legal team, NASA's decision to override the automatic stay was one of the rare cases upheld at the Department of Justice Court of Federal Claims.[387]

Collaborative Efforts

The award of the CRS contracts to the COTS competitors facilitated efforts within the ISS Program Office to ensure the companies' vehicles would be prepared for their future ISS resupply flights. The transportation integration teams that verified that the COTS partners met integration requirements were able to transition their technical knowledge of the

Dragon and Cygnus spacecraft to the management of the CRS contract. Lueders explained how, by "leverag[ing] off of that work that had already been done … we were able to optimize our resources and the contractors' resources, and then optimize how we were relating with Alan's [COTS] folks too."[388]

After the CRS award, Lueders and TIO worked "hand-in-glove" with Lindenmoyer and the COTS team in encouraging the commercial partners to meet their technical milestones. The two offices held joint quarterly review meetings to present a united NASA front, sometimes playing "bad cop, good cop," with the commercial partners in order to encourage their development.[389] Antonio L. Elias, Executive Vice President and Chief Technical Officer of Orbital, observed that C3PO functioned as a "lubricant" for the ISS Program Office and commercial partners "to mesh together."[390] While C3PO maintained the role of investor, aiding development but offering payment only upon milestone completion, Lueders' office was able to enforce stricter requirements in accordance with the terms of the CRS contracts. Lueders reported that, "Honestly, it was a great, great collaboration between us."[391]

As with the definitions of requirements, the ISS Program Office worked flexibly with the commercial partners to schedule their resupply missions under the CRS contract. Even after the ISS office verified that vehicles conformed to SSP 50808, vehicles could not fly to the International Space Station at will. The ISS office maintained a complex schedule for all visiting vehicles slated to resupply the orbiting laboratory: Soyuz, Progress, ATV, HTV, and

International partners provided supplies to the ISS after America's Space Shuttle Program ended in July 2011. The European Space Agency built five Automated Transfer Vehicles (ATV), pressurized modules with a cargo capacity of almost 17,000 pounds. Shown above is the Jules Verne, the first ATV that launched March 9, 2008, and docked with the ISS on April 3. On September 29, 2008, as it reentered the Earth's atmosphere, the ATV incinerated as planned.

now Dragon and Cygnus. Further complicating matters was the fact that ISS had contracted missions for vehicles that did not yet exist in flight-ready form. As the commercial partners' technical milestones continued to slip, resulting in an almost three-year development delay from original projections, the ISS office adjusted its schedules and cargo manifests to accommodate the necessary resupply.

TIO approached the problem from a position of trying to aid and encourage what they recognized was a very demanding and challenging task for private industry. Lueders used the term "balance" to describe NASA's approach to securing the contracted delivery services without being so overbearing as to prevent the companies from being "healthy" enough to carry out their missions. Instead of "driving them into the ground with launch slip costs," the ISS team viewed the commercial partners as such, and arranged at the beginning of the contract to be able to negotiate launch schedules and missions profiles to better suit the development needs of both the companies and ISS.[392] In one case, for example, a schedule slip benefited both SpaceX and the ISS office: ISS also needed additional time to determine how best to robotically extract external cargo from the Dragon spacecraft.

Augmented Funding

In fiscal year 2011, Congress took the rare and noteworthy step of approving the addition of $300 million to the C3PO budget. (More details of the augmentation can be found in Chapter 4: Program.) The COTS team reviewed multiple potential uses of these unanticipated funds. Actions under consideration included modifying the ISS Commercial Resupply Services contracts (for example funding early cargo delivery, and/or building additional capsule mockups for training) and giving money to other NASA organizations that supported the infrastructure for commercial cargo delivery.[393]

As part of the original COTS agreements, NASA's contributions to the commercial partners were fixed at the beginning of the program, and any cost increases incurred while pursuing the milestones were solely the responsibility of the commercial

partners. Therefore, when additional funding became available, C3PO determined that the best application of these funds was to add milestones to the commercial partners' COTS Space Act Agreements specifically to reduce technical risk and accelerate development of their respective systems to deliver the needed cargo to low-Earth orbit.[394]

At the time of the augmentation, COTS was still "owed" $12 million in funding from the original $500 million allocation. Therefore, the program expected to receive $312 million in fiscal year 2011 ($300 million plus $12 million) for augmentation and original program milestones. Instead, C3PO received only a $300 million allocation. This meant the program had to use $12 million of the $300 million augmentation for original milestones, leaving $288 million in available additional funds.[395]

C3PO transferred $17.5 million to the ISS Program Office in order to allow ISS to purchase cargo on the COTS demonstration missions, a service not permitted under the terms of the COTS Space Act Agreements.[396] This left about $118 million worth of additional milestones to be added to each partner's Space Act Agreement. From December 2010 to May 2011, these additional milestones, including a thermal vacuum test for SpaceX and an additional test flight for Orbital, were negotiated with the partners and added to their respective Space Act Agreements.[397]

Engineers in C3PO saw the advantage of this mid-stage injection of funds, noting that at that point the strengths and weaknesses in project development were becoming more apparent, and "you can start plugging holes in where there are big weaknesses."[398]

Federal Aviation Administration

While NASA's safety community largely accepted how operations pertaining to the ISS were conducted, some noted the Agency's lack of jurisdiction in the case of an accident on Earth.[399] Because the industry partners' launches and reentries were commercial, not government activities, these fell under the authority of a different federal agency, the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST).

The space policy that President Ronald Reagan established in the early 1980s (before the *Challenger* accident) strongly supported commercial space enterprises. The 1984 Commercial Space Launch Act allowed and encouraged the development of private launch and reentry services, and created the AST under the Department of Transportation "to form a single one-stop shop that would facilitate the process of a commercial entity conducting a launch."[400] The Office was charged with the dual tasks to 1) regulate the U.S. commercial space transportation industry, and 2) "encourage, facilitate, and promote commercial space launches and reentries by the private sector."[401] In 1995, AST was transferred to the FAA, where the office continues to both promote commercial space and ensure compliance with regulations for all launch and reentry operations conducted on U.S. soil and abroad by U.S. companies.

Working with the U.S. Air Force, AST codified the military's best practices into common safety standards for commercial companies. The resulting "big, fat book of regulations" was added to the list of requirements the COTS commercial partners needed to comply with in order to launch their ISS demonstration missions.[402] Although these regulations might be seen as an additional burden, according to Dr. George C. Nield, FAA Associate Administrator for AST, the FAA also helped new companies by providing a known regulatory environment that could be accounted and planned for in companies' business plans.[403] For more established companies such as Orbital, employees were already accustomed to the licensing process, as it had become part of their regular launch routine.[404]

Regulations

Any private entity launching from the U.S., or any U.S. company conducting launches abroad, is required to demonstrate that the operation will not "jeopardize public health and safety, or safety of property" in order to receive either a launch or reentry license, an experimental permit, or an operator's license.[405] These regulations apply only to launch and reentry safety. That is, they are intended to protect the general public and property on the ground only, not any human participants of any potential suborbital or orbital flights.

The requirement for COTS partners to obtain launch licenses from the FAA was understood from the beginning of the initiative, and was reflected in both COTS announcements. During the competition, an engineer from the FAA reviewed potential partners' licensing plans, and "let NASA know whether the company had already started discussions with the FAA."[406]

Credit: George Nield

NASA and the Federal Aviation Administration (FAA) have partnered to enable American industry to provide the government and private-sector customers with safe, reliable, and cost-effective transportation to low-Earth orbit. (Left) Dr. George Nield, FAA Associate Administrator for Commercial Space Transportation, and Charlie Bolden, NASA Administrator, both participated in the 2012 Commercial Space Transportation Conference.

Limiting the number of regulations for the private sector was a deliberate strategy designed to encourage the incipient commercial spaceflight sector. The 2004 Commercial Space Launch Amendments Act updated the legislation signed 20 years prior and included a "learning period" from 2004 to December 2012 that limited the FAA's ability to impose regulations for crew and spaceflight participants.[407] In February 2012, Congress extended this moratorium until October 2015.[408]

Since 1988, the U.S. government has also provided indemnification to commercial providers of launch services. In the case of an accident, the company will be only financially liable for what has been determined through the licensing process as "maximum probable loss." Any further amount will be the responsibility of the U.S. government.[409] Both government indemnification and the moratorium on regulations are intended to encourage the industry and make U.S. companies more competitive internationally, and in theory will be phased out as commercial launch companies gain more experience in space operations.

Promoting Commercial Space

In addition to regulating launch and reentry operations, the second half of the FAA Office of Commercial Spaceflight's mandate is to encourage and promote the commercial spaceflight sector. Nield has continued AST's mission by, among his other duties, attending numerous commercial spaceflight and NewSpace conferences to meet with industry. Other activities that AST conducts to promote the commercial spaceflight sector include: hosting meetings of the Commercial Space Transportation Advisory Committee (COMSTAC), holding an annual Commercial Space Transportation Conference, publishing economic impact studies and launch forecast reports, and reaching out to potential launch license applicants.[410]

Nield explained, "We don't ever compromise safety, but if you look at the encourage/facilitate/promote role, we're trying to listen and understand what kinds of policies or activities the government is doing that are turning out to be obstacles to the industry."[411] By maintaining and encouraging open lines of communication with industry representatives, Nield was able to earn the trust of commercial companies and overcome any initial suspicions they may have had about working with a government agency.

As with its work with the ISS Program, C3PO's collaboration with the FAA proved pivotal to the success of COTS. The cooperative, partnership philosophy of both the ISS Transportation Integration Office and the FAA Office of Commercial Spaceflight mirrored the COTS approach to working with the commercial sector—enforcing safety where necessary, but also remaining cognizant of the need to critically examine rules and regulations.

First Steps Toward Commercial Crew

Commercial Crew Development

Commercial Crew Program

chapter 7

With the development of ISS cargo delivery services underway, in 2009 the Commercial Crew & Cargo Program Office (C3PO) moved forward with the development of the technologies needed for commercial crew transportation. C3PO was allocated $50 million of stimulus funds from the 2009 American Recovery and Reinvestment Act "to support efforts within the private sector to develop system concepts and capabilities that could ultimately lead to the availability of commercial human spaceflight services."[412]

Commercial Crew Development

Following the same pattern as the two COTS competitions, on 10 August 2009, NASA issued the Commercial Crew Development (CCDev) Announcement for potential industry partners interested in entering into funded Space Act Agreements to develop the vehicles and technologies needed for crew transportation. C3PO also began formulating draft requirements and standards for commercial crew safety.[413]

Of the 36 companies that submitted proposals by the September 22 deadline, 18 made it through the Step 1 evaluation screening, including HMX Inc., a name familiar from NASA's Alternate Access to Station effort in 2000.

Eight were then selected as finalists to continue to the next step of due diligence: Ball Aerospace, Blue Origin, The Boeing Company, Paragon Space Development Corp., Sierra Nevada Corp., Space Exploration Technologies Corp. (SpaceX), United Launch Alliance (ULA), and XCOR Aerospace.

For Selection Authority Geoffrey L. Yoder, discriminating factors included whether or not the proposal would advance technology for crew transportation within the approximately one-year timeframe of the agreement, as well as companies' connections to other members of industry.

"By engaging with potential customers early in development, there is a higher likelihood that its development activities will contribute to accelerating a commercial crew transportation capability," Yoder wrote in his Selection Statement.[414] For example, multiple companies' proposals relied on ULA's rockets to launch their vehicles and would be ULA customers, indicating a promising market for the launch provider.

Yoder also looked for "tangible test or demonstration missions," and aimed to include a variety of different types of technology systems in the selection portfolio.[415] NASA sought to encourage the development of capabilities widely applicable to a range of spacecraft.

Based on these criteria, on December 8, 2009, five companies were selected for funded Space Act Agreements. As in the COTS program, these awards were to be paid in increments upon the successful completion of the agreements' predetermined milestones. The largest award went to the Sierra Nevada Corp., which received $20 million for the

development of the Dream Chaser spacecraft, the only proposed lifting body system. The Dream Chaser was originally developed by COTS competitor SpaceDev, Inc., which Sierra Nevada acquired in 2008.

Next, Boeing received $18 million to develop the Crew Space Transportation (CST)-100 capsule. NASA cited Boeing's "experience as a systems integrator and its previous work on the NASA human spaceflight program," as one of the reasons for the company's selection.[416] Yoder interpreted Boeing's use of the existing Atlas V rockets as a strength, but in the COTS Round 2 competition that took place in 2008, Selection Authority Richard Gilbrech saw this as a weakness because Boeing would be dependent on an external supplier.

ULA, a joint venture between Boeing and Lockheed formed in December 2006, received $6.7 million for an Emergency Detection System for human rating its launch vehicles. Blue Origin, a startup founded by Amazon.com, Inc. mogul Jeff P. Bezos, was awarded $3.7 million for its "pusher" Launch Abort System and composite pressure vessels. Finally, Paragon Space Development Corp. received $1.4 million for a new modular Environmental Control and Life Support System.[417]

According to the CCDev Space Act Agreements that were signed by Yoder on January 30, 2010, all the companies' milestones were originally scheduled for completion by August of that year, giving participants a little over half a year to pursue their development programs.

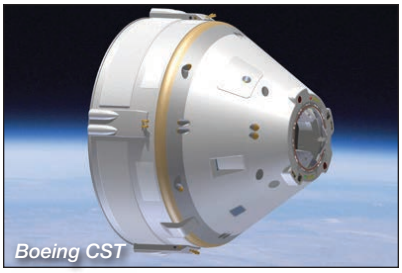
C3PO brought in two additional project executives to monitor and support these new commercial partners. Scott D. Gahring, aided by his Assistant Project Executive Stokes McMillan, served as the NASA Project Executive for Blue Origin and Sierra Nevada. Donald W. Totton served as the NASA Project Executive for Boeing, Paragon, and ULA, and later continued to support the Agency's commercial initiatives in the Systems Engineering and Integration Office of the Commercial Crew Program.

In February and March 2010, all the CCDev SAAs were amended to accommodate a three-month extension of the milestone completion dates. Sierra Nevada and Paragon completed their last milestones in December 2010, and Boeing completed its last milestone in February 2011.

Both the Blue Origin and Boeing SAAs were further amended to extend the deadline for completion of their CCDev milestones to April 30, 2011. C3PO Manager Alan J. Lindenmoyer signed the ULA letter of completion on April 5, about three weeks before the deadline, and Blue Origin had one uncompleted milestone remaining when its SAA expired at the end of the month.[418]

With this first step toward the development of key technologies needed for future crew transportation systems successfully completed, the Agency was ready to proceed with its program to support more full-scale development of commercial crew vehicles. These five companies now had the opportunity to participate in the CCDev2 competition announced in October 2010 and awarded in April 2011. CCDev2 marked a change in strategy for NASA's commercial endeavors, as the Agency elected to administer its future commercial programs from the Kennedy Space Center (KSC) in Florida.

Sierra Nevada


Boeing CST

United Launch Alliance

Blue Origin

Paragon Space Development

Five companies (above) entered into funded NASA Space Act Agreements for Commercial Crew Development (CCDev). As with the COTS program, incremental funding was paid based upon the successful completion of predetermined milestones.

Commercial Crew Program

The new Commercial Crew Program (CCP) was established at KSC "to help the aerospace industry in the United States develop space transportation systems that can safely launch astronauts to the International Space Station (ISS) and other low-Earth orbit destinations."[419] CCP began with two follow-on commercial programs—Commercial Crew Development 2 (CCDev 2) and Commercial Crew integrated Capabilities (CCiCap).

Credit: NASA/Robert Markowitz

Kathryn Lueders, Acting Program Manager for NASA's Commercial Crew Program (CCP), answered questions during an event held by CCP partner Boeing. Prior to this position, Lueders worked closely with the C3PO team while she served as manager of the ISS Program's Transportation Integration Office, responsible for the commercial cargo resupply missions to the International Space Station. She was also responsible for integration of the international partner vehicles traveling to the ISS. In her current role, Lueders oversees the NASA CCP helping private companies to develop a new U.S. capability to carry astronauts into low-Earth orbit and to eventually take crews to the International Space Station.

Credit: SpaceX

The crewed variant of the SpaceX Dragon will have a capacity for seven seats and is being designed with an advanced launch escape system. The company has plans for a propulsive landing system to allow for a gentle touchdown to the ground.

Credit: Sierra Nevada Corp.

Developed by the Sierra Nevada Corporation, the Dream Chaser will launch vertically on an Atlas V rocket and automatically land horizontally on a runway. The reusable lifting-body spacecraft is designed to carry a crew of up to seven people to and from low-Earth orbit.

The KSC-based office applied some of the model first enacted by C3PO, including the use of funded Space Act Agreements, as well as partnerships with multiple, competing companies. In April 2011, CCDev 2 split $270 million between Boeing ($92.3 million), Sierra Nevada ($80 million), SpaceX ($75 million), and Blue Origin ($22 million) for further development of their crewed systems. In August 2012, for the CCiCap Space Act Agreements NASA narrowed these four competitors to three: Boeing ($460 million), SpaceX ($440 million), and Sierra Nevada ($212.5 million).[420]

However, reasoning that carrying humans, not just cargo to ISS was of a fundamentally different nature, the Commercial Crew Program at KSC chose to utilize traditional procurements contracts in addition to SAAs. In December 2012, NASA awarded Certification Products Contracts (CPC) to Boeing, Sierra Nevada, and SpaceX, in the amount of approximately $10 million each.[421] These FAR-based contracts ensured that NASA was able to provide what it deemed the necessary oversight for the safety of crewed systems. So although NASA has retained some elements of the model established by the COTS team at JSC, in other areas it has found the need to revert to more traditional means of working with the private sector.

NASA anticipated that the resulting commercial crew "space taxi" services would be available by 2017.[422]

Credit: Boeing

Boeing's Crew Space Transportation (CST)-100 spacecraft floated to a landing during a parachute drop test at the Delamar Dry Lake Bed near Alamo, Nevada. The CST-100 is designed to transport people and cargo to the ISS.

Legacy

From Contingency to Dependency

The COTS Model: A New Way

Conclusion

chapter 8

After eight years of operations, the NASA Commercial Crew & Cargo Program Office (C3PO) at the Johnson Space Center (JSC) succeeded in inaugurating a new era in spaceflight. With its Commercial Orbital Transportation Services (COTS) initiative, C3PO demonstrated that the space agency could rely on non-government providers for safe, reliable, and cost-effective cargo delivery services to and from the International Space Station.

From 2005 to 2013, C3PO acted as an investor and advisor with three separate and distinct companies: Space Exploration Technologies Corp. (SpaceX) (from 2006 to 2012), Rocketplane Kistler (from 2006 to 2007), and Orbital Sciences Corp. (from 2008 to 2013). Although Rocketplane Kistler was unable to complete its milestones, both SpaceX and Orbital developed space transportation systems capable of resupplying the International Space Station (ISS) after Space Shuttle retirement. Less than a year after the last Shuttle flight, the first cargo transported by a U.S. commercial provider arrived at the ISS.

In addition to these needed ISS resupply services, the COTS program saved taxpayer funds. While the space agency invested a total of about $788 million in partners' development programs, industry provided the majority of funds (approximately $1 billion) for the two new launch vehicles, automated cargo carriers, and ground systems that resulted from the government-industry collaboration.

The partnerships also provided a boost to the nation's economy by creating jobs in the commercial space sector and enabled the U.S. to recapture a share of the global launch market. For the companies, the spacecraft developed as a result of the agreements gave them the opportunity to capitalize on potential new markets.

"The commercial space industry will be an engine of 21st century American economic growth and will help us carry out even more ambitious deep space exploration missions," said NASA Administrator Charles F. "Charlie" Bolden. "America's best days in space exploration are ahead of us thanks to the grit and determination of those in government, and the private sector, who dare to dream big dreams and have the skills to turn them into reality."[423]

From Contingency to Dependency

At the time of the first COTS award in 2006, Agency officials at NASA Headquarters in Washington, DC, envisioned that commercial companies would take over low-Earth orbit transportation services as a part of the overarching Vision for Space Exploration. Announced in January 2004, this Vision put the nation on a path of exploration to the Moon, then on to Mars, with NASA building powerful spacecraft for a new program called Constellation. Included in the plan was a relatively small piece of NASA's mission: "to pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration missions beyond low-Earth orbit."[424]

NASA Administrator Michel Griffin allocated only $500 million, spread over five years, of the Agency's

multi-billion dollar budget for the COTS program. Griffin intended that the vehicles developed under this initiative would help provide ISS resupply at the end of the Space Shuttle program. Because of the relatively small allocation, members of C3PO at JSC saw that COTS was somewhat "off the radar" for many policy makers in Congress. They understood the development of commercial transportation capabilities as a "side bet" or "back burner" option for ISS resupply.[425] In other words, COTS was a "high-risk" contingency being pursued as a backup for the vehicles being developed under Constellation or the Agency's international partner cargo resupply vehicles.[426]

However, by the spring of 2011, NASA reported to Congress that the Agency was "depending on our commercial cargo partners. We need their COTS development efforts to succeed so that they can begin providing cargo resupply to the International Space Station." In simple terms, the commercial cargo providers were "too important to fail."[427]

Although there is no clear consensus on when exactly Congress began to take more notice, team members cited mounting delays within the Constellation Program as bringing greater attention to the COTS program and its objectives.[428]

The Commercial Resupply Services (CRS) contracts awarded in December 2008 were another contributing factor. Under the terms of the CRS contracts, Orbital was awarded a contract worth $1.9 billion to deliver 8 flights of cargo to ISS. SpaceX was awarded a contract worth $1.6 billion for 12 CRS delivery flights using its capsule-shaped Dragon spacecraft.

Credit: NASA/Bill Ingalls

President Barack Obama toured the SpaceX processing facility in Cape Canaveral, Florida, along with founder and CEO of the company (right) Elon Musk, in April 2010. On that trip, the President also spoke at the NASA Kennedy Space Center where he delivered remarks on the new course his administration was charting to maintain U.S. leadership in human spaceflight. In his speech, the President emphasized partnerships with the private sector to "make getting to space easier and more affordable."

Then, President Barack H. Obama, inaugurated in January 2009, steered U.S. space policy on a different course by cancelling the Constellation Program in February 2010 and placing significantly more emphasis on commercial space activities. Obama directed Bolden, the new NASA Administrator, to lead a program that would send astronauts to an asteroid by 2025 instead of returning to the Moon, and facilitate the emergence of a commercial space industry.

A few years later the Obama administration policy was reemphasized in a statement released by the White House Office of Science and Technology Policy: "The growing potential of America's commercial space industry and NASA's use of public-private partnerships are central to President Obama's strategy to ensure U.S. leadership in space exploration while pushing the bounds of scientific discovery and innovation in the 21st century."[429]

Utilization of the International Space Station

The U.S. segment of the ISS was officially designated a National Lab in the NASA Authorization Act of 2005, and since then both Congress and NASA have emphasized maximizing the Station as a scientific research platform once assembly was completed in May 2011. The COTS commercial partners have become "essential to ensuring the capacity to ferry experiments to and from the Station" with their new low-Earth orbit transportation systems.[430] All current and planned U.S. experiments aboard the Station will be facilitated in some way by a CRS mission and a COTS partner.[431]

ISS Transportation Integration Office Manager Kathryn L. Lueders reflected on how the SpaceX Dragon spacecraft has been able to not only transport additional supplies to Station—graduating from more basic internal pressurized cargo to the addition of external pressurized items and powered units for storing scientific experiments and samples—but also return some of these back to Earth. By the fourth CRS mission, SpaceX planned to transport live mice and rats to Station, a capability not available on existing Progress, ATV, or HTV vehicles.[432]

Former ISS Program Manager Randolph H. Brinkley similarly applauded the Station's new capabilities for scientific inquiry. In fact, Brinkley cited his concern for the scientific utility of the ISS without reliable up- and downmass capability as one of the primary reasons he joined the Rocketplane Kistler venture as its president. He stated that this is "a gap that's just now being closed" after the retirement of the Space Shuttle in July 2011.[433]

In addition to using the commercial vehicles for NASA experiments, advocates of this new way of doing business, including William H. "Bill" Gerstenmaier, NASA's Associate Administrator for Human Exploration and Operations, stated how the ISS can serve as a gateway market for private science customers to follow.[434]

Stimulating the Commercial Use of Space

In August 2011, NASA signed a cooperative agreement with the Center for the Advancement of Science in Space (CASIS), tasking the nonprofit to manage non-NASA research on the ISS. CASIS is now working to find commercial opportunities for Station by marketing the Station's capabilities to the science community and using the organization's established contacts to "match investors and researchers."[435] Proposals submitted for Station must meet both scientific and economic criteria, i.e., market viability—the same dual criteria used to select the COTS commercial partners. NASA has also collaborated with NanoRacks, a venture that has been successful selling small payload accommodation on, and small satellite launches from ISS.[436]

Ideas for commercial research on ISS have focused particularly on pharmaceuticals research that can benefit from microgravity experiments, such as new vaccines and learning from changes in gene expression that occur in space.[437] Gerstenmaier foresaw a future in which these experiments aboard Station became so valuable that all low-Earth orbit activities were funded by pharmaceutical companies, freeing NASA to explore beyond.[438]

Credit: NASA/Bill Ingalls

Lori Garver, NASA Deputy Administrator, and Robert T. Bigelow, President and founder of Bigelow Aerospace stood next to the mock-up of the Bigelow Expandable Activity Module (BEAM) during a media briefing on January 16, 2013. At this event, Garver announced that NASA had awarded a $17.8 million contract to Bigelow Aerospace to provide a prototype of the expandable habitat to be added on the ISS for a two-year technology demonstration. The expandable habitat is scheduled to arrive at the International Space Station in 2015.

NASA also has announced plans to expand the International Space Station itself in the near future. In January 2013, NASA signed a contract with Bigelow Aerospace, founded by Budget Suite Hotels executive Robert T. Bigelow, to develop an inflatable space habitat that is scheduled to begin a two-year trial attached to ISS as early as 2015. Bigelow contracted SpaceX to launch the Bigelow Expanded Activity Module (BEAM) on a Falcon rocket.[439] As the market in low-Earth orbit matures, commercial space companies have begun buying services from one another.

Free-Fliers in Low-Earth Orbit

Phil McAlister, NASA Director of Commercial Spaceflight Development, observed that the government's investment resulted in "two low-cost launch vehicles, two autonomous spacecraft capable of delivering cargo and two privately developed launch facilities," providing a "very robust U.S. domestic cargo transportation capability."[440]

The COTS partners plan to use this newly-developed capability to offer microgravity services to the pharmaceutical industry and other markets in addition to the ISS. SpaceX has marketed the DragonLab free-flier variant of its orbital spacecraft to customers in the science community to house experiments in microgravity.[441]

Orbital officials have seen possibilities for using the Cygnus capsule to sell "hosted payloads" to NASA and other government scientists. (In its current form, Cygnus can only send data back to Earth because the capsule is destroyed upon reentry to Earth's atmosphere.) Potential Orbital customers include researchers at the NASA Glenn Research Center studying how fire behaves in zero gravity conditions.[442]

According to Robert T. "Bob" Richards, Orbital Vice President of Human Spaceflight Systems, the company also looked into the potential to use components of the Cygnus capsule for "adjacent markets," for example utilizing the rendezvous sensors and technology for eventual satellite servicing.[443]

The COTS Model: A New Way

The COTS model developed and successfully executed by C3PO has proven an example of a new way for how NASA can cooperate with private industry. In addition to providing the space agency with a needed service to fulfill its mission to the ISS, innovative partnerships can benefit the government by achieving maximum return on investment from taxpayer funds.

Key features of the COTS model include limited NASA oversight, a flexible and streamlined acquisition process, and fixed-price incentives to hold cost and schedule. Lindenmoyer expanded on these and other key features of this form of public-private partnerships in a white paper that is included in the Appendix.

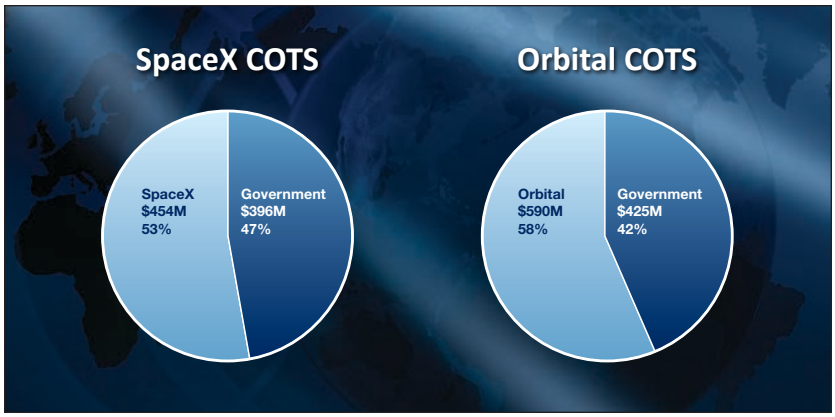
Return on Investment

In 2011, NASA Deputy Administrator Lori B. Garver emphasized how the Agency was "working to invest the Nation's valuable tax dollars to assure a healthier, more competitive industrial base … while creating new markets, new industries, and new jobs in order to advance our national security and economic future."[444]

Both the SpaceX and Orbital low-Earth orbit transportation systems were developed with a total NASA COTS investment of just $788 million ($500 original funding plus $288 million fiscal year 2011 augmentation). C3PO achieved maximum use of its limited budget by allocating over 93 percent of funds to partner milestone payments, with the rest dedicated to program management, technical support, and overhead.

And, by the end of the COTS program, NASA had provided less than one half of the cost for the commercial transportation systems' development and demonstration, as seen in the figures below. Note that the government investment for Orbital includes funding sources other than COTS that were contributed toward the launch and ground facilities at Wallops Island, VA.[445]

The NASA Air Force Cost Model (NAFCOM) estimate for the cost to develop the SpaceX Falcon 9 vehicle, based on the NASA environment and culture, ranged from as low



Government funding sources provided less than one half of the cost for the development and demonstration of two commercial transportation systems.

Credit: SpaceX

SpaceX completed its milestones for the COTS partnership with its C2+ mission, launched on May 22, 2012, from Cape Canaveral, Florida. Since then, SpaceX has captured a share of the global satellite launch market using the Falcon 9 developed under COTS.

as $443 million to as high as approximately $4 billion.[446] However the final cost for developing and demonstrating the Falcon 9 rocket was only about $400 million—up to 10 times less than projected.[447] Lisa P. Price, ISS Resources Branch Chief at JSC, reported that NASA was then able to acquire these U.S.-based cargo transportation services at a significantly lower cost than previous Space Shuttle flights.[448]

In a June 2009 report, the Government Accountability Office commended C3PO for its responsible use of government monies. Particularly noted was the very small percentage of the program's budget applied to management and overhead. The report also found that C3PO "adhered to critical project management tools and activities," describing how the COTS program did a creditable job of identifying, documenting, and mitigating risks; communicating with the commercial partners and providing them technical expertise; and by adhering to the established system of fixed-price milestone payments.[449]

Job Creation

The development of U.S.-based space transportation systems funded by the over $1 billion of combined government and industry funding of COTS encouraged job and economic growth in the domestic aerospace industry. For instance, in just one day in January 2013 SpaceX hired 90 new employees at its Hawthorne, California headquarters.[450] In July 2013, the Silicon Valley Business Journal reported that

SpaceX was looking for 200 additional employees to complement its 3,000 member team.[451]

On the East Coast, the Mid-Atlantic Regional Spaceport (MARS) utilized by Orbital Sciences Corp. for the launches of its Antares rocket has been credited for significant economic impact, as part of the overall Virginia space industry that "contributes $7.6 billion in annual direct economic output and directly supports 29,638 jobs."[452] Maryland Senator Barbara A. Mikulski estimated that the Orbital missions to deliver cargo to ISS would bring 500 additional jobs to the Eastern Shore.[453]

Launch Markets

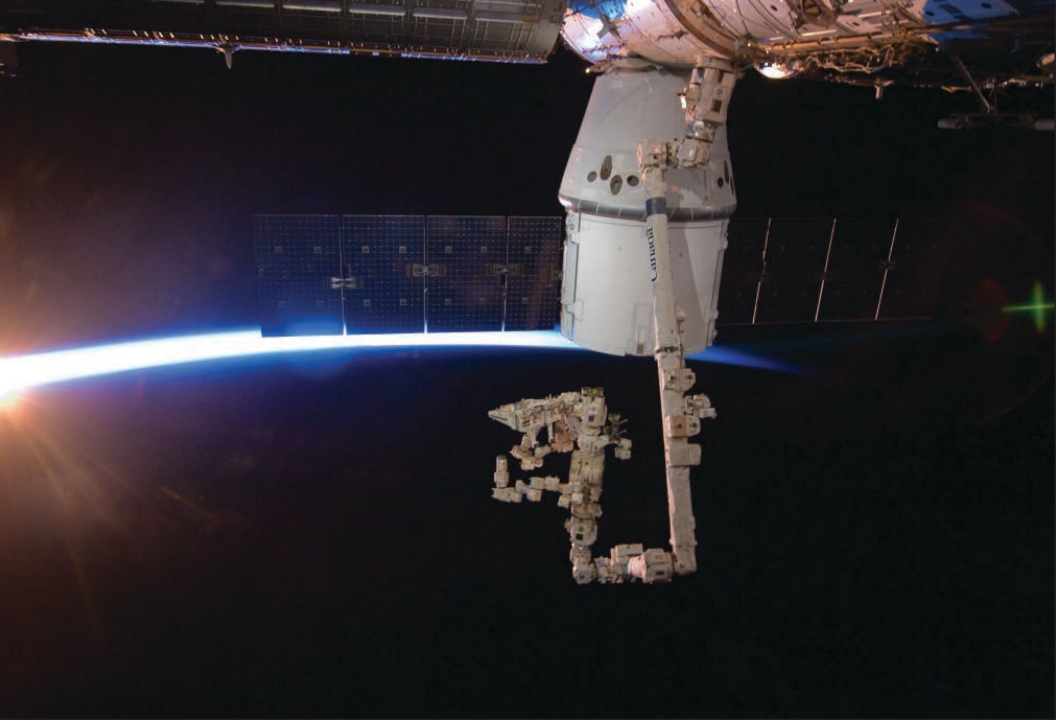
From its inception, one of the objectives of COTS was to "create a market environment in which commercial space transportation services are available to government and private sector customers."[454] As Sumara Thompson-King, NASA Deputy General Counsel, explained, "We didn't view COTS as just supporting NASA. We thought that there would be other entities, both in the government and in the commercial sector, that would use those services."[455]

While the space agency remains the only customer of low-Earth orbit delivery services, both SpaceX and Orbital have been able to sell launch services to customers outside NASA and the government.[456]

The question of U.S.-based launch capability was an important one for Marc G. Timm, COTS Program Executive at NASA Headquarters,

Credit: NASA/Bill Ingalls

Orbital Sciences Corp. launched its Antares rocket and Cygnus cargo spacecraft towards the International Space Station on September 18, 2013, from the Mid-Atlantic Regional Spaceport, NASA Wallops Flight Facility, Virginia. In addition to providing commercial logistics to ISS, Antares is a new launch vehicle to help the United States compete in the global launch services market.



Both COTS commercial partners reached their goal of providing cargo transportation systems that could resupply the ISS. (Top photo) In May 2012 the Dragon spacecraft launched on the SpaceX Falcon 9, separated from the rocket, then traveled to the International Space Station, where it was grappled and berthed to the Harmony node on May 25. (Bottom photo) Sixteen months later, Orbital Sciences Corp. launched its Antares rocket on September 18, 2013 with the Cygnus cargo capsule that moved into a low-Earth journey to the ISS. The cargo vehicle was berthed to the International Space Station 11 days later, staying 3 weeks before being released. The deliveries signified the end of the COTS agreements; now, both companies use the systems built under COTS to bring supplies to the ISS as part of NASA's Commercial Resupply Services contracts.

who observed that the availability of commercial rockets has allowed the U.S. "to become more globally competitive in the launch market."[457] Timm observed that the United States dominated the launch market in the 1980s, but by 2011 the U.S. government was the only purchaser of domestic launch services. The availability of the SpaceX Falcon and Orbital Antares rockets has the potential to bring some of those launches back to the U.S., along with some satellite manufacturing capabilities that have been outsourced in order to avoid the complications of dealing with U.S. International Traffic in Arms Regulations restrictions.[458]

As evidence of the growing domestic launch market, SpaceX has found both military and commercial customers for its Falcon 9 launch services—even prompting European-based Arianespace to increase the lift capacity of its Ariane rocket to make it more cost competitive.[459] The Pentagon's $900 million award of indefinite-quantity, indefinite-delivery contracts to Lockheed, Orbital, and SpaceX made headlines in December 2012, as a significant contract awarded to the COTS partners.[460]

In addition to this military contract, Orbital hopes to find new customers for Antares, particularly those that previously would have used the phased-out Delta II rocket. The company has also contracted secondary launch payloads on Antares missions to ISS.[461]

Conclusion

Throughout the first five decades of the U.S. space program, the space transportation systems NASA depended on to pursue its goals of exploration were owned and operated by the government. Space policy analyst Jeff Foust observed that, "For a long time … we've seen a lot of promises and PowerPoint presentations about proposed (private) spacecraft," continuing, "Now we're seeing those PowerPoints turn into actual hardware."[462]

Only time will tell if this most recent surge of promising activity in the private spaceflight sector will produce the much-awaited thriving commercial space transportation industry. However, there are some indicators pointing to an optimistic future. Anticipating the commercial space industry's growing momentum, Embry-Riddle Aeronautical University offered the first degree program in Commercial Space Operations in the fall of 2013.[463] And, a report by the Space Foundation stated that the world space economy grew 6.7 percent from 2011 to 2012, especially in the area of commercial space infrastructure and support.[464]

With this initial success achieved, the direction of commercial enterprise in space still contains unforeseen market potential. As Harvard Business School professor Clayton M. Christensen observed in his book *The Innovator's Dilemma*, "Not only are the market applications for disruptive technologies *unknown* at the time of their development, they are *unknowable*."[465] What is known at this stage is that COTS has played an important and demonstrable role in the burgeoning commercial space transportation market.

In its 2013 Annual Report, the NASA Aerospace Safety Advisory Panel (ASAP) led by Vice Admiral Joseph W. Dyer, USN (Ret.) included statements emphasizing the success of the COTS program. The report pointed out that it "was not simply the use of fixed-price Space Act Agreements that led to the Program's success, although that helped to enable the successful outcome. Rather, NASA did a number of things right along the way, such as maintaining excellent program management, appointing well-qualified technical representatives [as project executives], providing the right amount of insight, requesting the right amount of information, and having the right number of Government attendees at industry meetings."[466]

Calling the COTS program "extremely successful," the ASAP agreed that while it would not be appropriate for every government program to use a COTS-type management philosophy, "we would encourage NASA (and other Government agencies) to consider adopting similar approaches where possible."[467]

NASA Headquarters acknowledged this new way of business by revising NASA Policy Directive (NPD) 1000.5, the Policy for NASA Acquisition, to recognize the role that partnerships can play in meeting the space agency's mission needs. This new approach required NASA to "consider the full spectrum of acquisition approaches," including procurement, grants, cooperative agreements, and Space Act Agreements.[468] NASA has also taken steps to establish a Partnership Integration Council, chaired by the Deputy Administrator, to foster consistent guidance, governance, and processes across the Agency when considering new industry partnerships.[469]

Building on the successful legacy of COTS, in early 2014, NASA's Human Exploration and Operations Mission Directorate began several initiatives to continue partnerships with the commercial space industry, including Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) opportunities to spur commercial cargo transportation capabilities to the surface of the moon, and Collaborations for Commercial Space Capabilities (CCSC) to help pioneer paths to Mars and other deep space destinations.

Though not complete, commercial space advocates have witnessed a "victory" in the NASA cultural change in progress.[470] In the words of NASA Deputy Administrator Lori B. Garver, NASA is "like a big ship and we don't turn easily, but when we do it's also hard to turn back. This program, while just a teeny-tiny fraction of our budget, has caused a shift in Agency thinking, and hopefully the thinking of all of us about how we're going to go forward in space."[471]

Said Lindenmoyer, "NASA knows all too well there will be failures and setbacks ahead. But we also know that through the trusted partnerships we have forged with our industry colleagues, problems will be solved and a new era in commercial space will begin."[472]

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COMMENTARY

EDITORIAL

A Space Policy Success Story

SES-8 Launch is Victory Lap for COTS Program

The launch Dec. 3 of the SES-8 telecommunications satellite atop a Space Exploration Technologies Corp. (SpaceX) Falcon 9 v1.1 rocket put an exclamation point on NASA's Commercial Orbital Transportation Services (COTS) program, which had already succeeded in its original goal of spurring development of commercial logistics services to the international space station.

Technically, COTS concluded several weeks earlier with the successful delivery of supplies to the space station by Orbital Sciences Corp.'s Cygnus capsule, which was launched by that company's new Antares rocket. The SES-8 launch, as Falcon 9's first purely commercial mission, extended the benefit of COTS beyond the space station, and in doing so solidified its legacy as an unqualified success story in U.S. civil space policy.

In that regard, COTS stands out in stark contrast to the nation's continued lack of a cohesive long-term human spaceflight strategy.

COTS was hatched by the administration of former U.S. President George W. Bush to leverage the private sector's willingness to invest in new rockets and capsules to reduce U.S. dependence on Russia for space station resupply services following the retirement of NASA's space shuttle. It was one of the few elements of Mr. Bush's space policy that was fully embraced by his successor, President Barack Obama, who took it a big step further by adopting a similar approach to restoring U.S. astronaut crew launching capabilities.

For a taxpayer investment of $850 million, NASA now has two operational space station cargo delivery systems. SpaceX successfully completed its COTS flight demonstration program in 2012 and has since carried out two of a planned 12 flights to station under the follow-on Commercial Resupply Services contract with NASA; Orbital is scheduled to conduct its first post-COTS resupply mission in December.

Meanwhile, notwithstanding questions surrounding the long-term availability of Antares, the U.S. government has at its disposal two new and potentially lower-cost launch vehicles that probably wouldn't have been developed without COTS. For its part, SpaceX is competing for a contract to launch astronauts to station aboard Falcon 9 and also is angling for a piece of the national security launch business currently monopolized by United Launch Alliance.

COTS is not without its critics, who point out that the program took longer and cost more than expected to get the desired results. But traditionally managed government space programs of this scale rarely come in on time and budget, and fewer still offer such direct ancillary benefits both for the government and commercial sector. SpaceX has amassed an impressive backlog of commercial missions while offering a dual-launch option for a new class of lightweight electric-propulsion satellites that could change the economics of the satellite telecommunications industry.

The success of COTS has encouraged NASA to explore whether a similar government-industry co-financing model can be successfully applied to other civil space endeavors. The agency issued a solicitation in June and is reviewing industry ideas in areas that range from lunar exploration to communications, although it remains to be seen what agency activities and missions might lend themselves to a COTS-like approach.

The Commercial Resupply Services program is still in a relatively early phase, and there are bound to be some hiccups as SpaceX and Orbital execute on their contracts. But having successfully completed their COTS flight demonstrations, the companies are already well on their way to securing the program's legacy as a winner for both government and industry.

Three months after the last COTS demonstration mission, SpaceNews printed the above editorial, calling COTS a success and stating that the two partners were "well on their way to securing the program's legacy as a winner for both government and industry."[473] The figure of $850 million includes the total of approximately $800 million received for the COTS cargo demonstrations, plus the $50 million allocation for the Commercial Crew Development (CCDev) Program.

Appendix

Acknowledgments

COTS Model for NASA Public-Private Partnerships

Chronology

COTS Oral History Interviews

Bibliography

Endnotes

Acknowledgments

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C3PO thanks Perry Jackson of the JSC Graphics group for his design of this book; and to John Bretschneider and Todd Hegemier for their assistance in gathering information.

COTS Model for NASA Public-Private Partnerships

Alan Lindenmoyer
Manager, Commercial Crew & Cargo Program
April 18, 2010

Background

In 2004, President Bush established the U.S. Space Exploration Policy which called for a return to the moon by 2020 and the Space Shuttle to be retired by the end of 2010 after completion of the International Space Station (ISS) assembly. Since the shuttle was planned to provide routine crew rotation and cargo resupply services throughout the service life of the station, this led to a shortfall of ISS resupply capabilities and a gap in U.S. human spaceflight. The Progress, HTV, and ATV International Partner cargo transportation capabilities were no longer sufficient to meet the logistics needs of the station and the ISS would become dependent on the Russian Soyuz vehicles for crew rotation and rescue until the Constellation vehicles became operational.

Soon after Mike Griffin became the new NASA Administrator in 2005, he challenged U.S. private industry to develop cargo and eventually crew space transportation capabilities that could meet the needs of the ISS. The Administrator established the Commercial Crew & Cargo Program Office (C3PO) at JSC under the Exploration Systems Mission Directorate (ESMD) and allocated $500 million over five years to stimulate the development and demonstration of commercial capabilities. Once demonstrated, NASA would purchase the emerging services to meet the U.S. obligations for servicing the ISS soon after the shuttle was retired in 2010.

Introduction

For over 50 years NASA has been the vanguard of human spaceflight. From the first flights of Mercury to a permanent presence on the International Space Station, NASA and its industry partners have pioneered some of the greatest accomplishments in history. The resulting technology spinoffs coupled with American ingenuity and entrepreneurial opportunities have transformed our world. These spinoffs are typically what come to mind when one speaks of the *commercialization* of space technology.

But we have not seen the growth of the commercial space transportation industry as we have with the first 50 years of commercial aviation. The commercial space communications sector has grown into a thriving multi-billion dollar industry and we have purchased commercial launch vehicles and payload services for many years now. The transportation of people to space remains an ambitious goal only achieved by governments due to extreme cost and risk barriers.

Since NASA blazed the trail for human spaceflight and the technology exists, the question becomes can industry capitalize on this opportunity if NASA seeds the market with funding to reduce the cost barrier and offers the space station as a predictable and reliable market for the transportation services? Perhaps with a substantial Government investment, NASA experience, and the promise of follow-on contracts, the industry will grow similarly to what was seen in the late 19th and early 20th centuries with railroads and aviation.

The premise of what became known as Commercial Orbital Transportation Services, or COTS, is different than the commercialization of a NASA technology transfer. COTS challenges American industry to develop, own, and operate their own space transportation systems that could be suitable for use by NASA and other customers. NASA would define the needs and safety expectations of the transportation service, but commercial companies would define the concept of operations and all of the detailed requirements and specifications for the entire system including ground operations, launch, orbital operations, reentry, and recovery. NASA would become a true partner in the commercial venture to provide specific expertise, lessons learned, and other requested information. We would also make our vast infrastructure of facilities and laboratories available on a marginal cost reimbursable basis.

The purpose of this paper is to define what is meant by *commercial* in the context of a space transportation system acquisition and the key features of what became the COTS model for NASA public-private partnerships.

U.S. Space Laws and Policies

Since it was NASA's intent to ultimately purchase *commercial* transportation services, as opposed to a Government developed capability, the C3PO acquisition planning team researched the Federal Acquisition Regulations (FAR) and other U.S. laws and policies for guidance on how to structure the acquisition. The key findings from this research are as follows.

According to the Commercial Space Act of 1998,

> …the Federal Government shall acquire space transportation services from U.S. commercial providers whenever such services are required in the course of its activities.
>
> …space transportation services shall be considered to be a commercial item.

The law allows exceptions to these requirements if the Administrator determines that…

> (1) a payload requires the unique capabilities of the Space Shuttle;
>
> (2) cost effective space transportation services that meet specific mission requirements would not be reasonably available from United States commercial providers when required;
>
> (3) the use of space transportation services from United States commercial providers poses an unacceptable risk of loss of a unique scientific opportunity;
>
> (4) the use of space transportation services from United States commercial providers is inconsistent with national security objectives;
>
> (5) the use of space transportation services from United States commercial providers is inconsistent with international agreements for international collaborative efforts relating to science and technology;
>
> (6) it is more cost effective to transport a payload in conjunction with a test or demonstration of a space transportation vehicle owned by the Federal Government; or
>
> (7) a payload can make use of the available cargo space on a Space Shuttle mission as a secondary payload, and such payload is consistent with the requirements of research, development, demonstration, scientific, commercial, and educational programs authorized by the Administrator.

These exceptions allowed NASA to use the Space Shuttle and International Partner vehicles for servicing the ISS throughout the assembly phase. However, with the promise of emerging new U.S. commercial capabilities, the Administrator determined that these exceptions may no longer apply after the ISS construction is completed and the shuttle is retired. This law defines U.S. commercial providers to be more than 50% owned by U.S. nationals or a subsidiary of a foreign company subject to certain conditions determined by the Secretary of Transportation.

The team then turned to the FAR which defines a *commercial item* to mean …

> (1) Any item, other than real property, that is of a type customarily used by the general public or by non-governmental entities for purposes other than governmental purposes, and—
>
> (i) Has been sold, leased, or licensed to the general public; or
>
> (ii) Has been offered for sale, lease, or license to the general public;
>
> (2) Any item that evolved from an item described in paragraph (1) of this definition through advances in technology or performance and that is not yet available in the commercial marketplace, but will be available in the commercial marketplace in time to satisfy the delivery requirements under a Government solicitation;
>
> (3) Any item that would satisfy a criterion expressed in paragraphs (1) or (2) of this definition, but for—
>
> (i) Modifications of a type customarily available in the commercial marketplace; or
>
> (ii) Minor modifications of a type not customarily available in the commercial marketplace made to meet Federal Government requirements. Minor modifications means modifications that do not significantly alter the nongovernmental function or essential physical characteristics of an item or component, or change the purpose of a process. Factors to be considered in determining whether a modification is minor include the value and size of the modification and the comparative value and size of the final product. Dollar values and percentages may be used as guideposts, but are not conclusive evidence that a modification is minor;
>
> (Note: only items 1-3 were excerpted here for brevity.)

The FAR Part 12 goes on to prescribe the procedures for the acquisition of commercial items which includes the use of firm-fixed price contracts and other provisions to streamline the acquisition process.

The Commercial Space Launch Act (as amended in 2004) is also relevant to commercial space acquisitions. The purpose of this law is…

> (1) to promote economic growth and entrepreneurial activity through use of the space environment for peaceful purposes;
>
> (2) to encourage the United States private sector to provide launch vehicles, reentry vehicles, and associated services by -
>
> (A) simplifying and expediting the issuance and transfer of commercial licenses;
>
> (B) facilitating and encouraging the use of Government-developed space technology; and
>
> (C) promoting the continuous improvement of the safety of launch vehicles designed to carry humans, including through the issuance of regulations, to the extent permitted by this chapter;
>
> (3) to provide that the Secretary of Transportation is to oversee and coordinate the conduct of commercial launch and reentry operations, issue permits and commercial licenses and transfer commercial licenses authorizing those operations, and protect the public health and safety, safety of property, and national security and foreign policy interests of the United States; and
>
> (4) to facilitate the strengthening and expansion of the United States space transportation infrastructure, including the enhancement of United States launch sites and launch-site support facilities, and development of reentry sites, with Government, State, and private sector involvement, to support the full range of United States space-related activities.

Item 3 is a key aspect of this law since historically most NASA missions were declared to be carried out by and for the Government and not subject FAA licensing.

Other important national policies and law include the U.S. Space Transportation Policy of 2005 which emphasizes use of launch vehicles manufactured in the U.S.; the National Space Policy of 2006 which reiterates U.S. commitment to encouraging and facilitating a growing entrepreneurial

U.S. commercial space sector; and the Iran, North Korea, and Syria, Nonproliferation Act (INKSNA) which restricts the purchase of Russian space systems supporting the ISS (restrictions currently waived through July 2016).

These laws and policies form the governing framework that must be addressed when planning any *commercial* space acquisition for NASA.

Acquisition Approach

The acquisition team determined that the cargo or crew transportation services needed to service the ISS were not yet available in the marketplace as a commercial item from U.S. commercial providers. Although launch services have been sold to the general public for many years, the additional capabilities necessary to deliver payloads to and from a human destination in low-Earth orbit (LEO) were not yet offered for public sale. The necessary complex technologies such as automated rendezvous and docking among other things, were under development and test, but were not at the maturity level needed to be purchased under a firm-fixed price commercial service contract.

At this point the team decided to pursue the acquisition of commercial space transportation capabilities in two phases. The first phase would be a period of development and demonstration to enable and accelerate advances in technology such that the emerging capabilities could evolve and become available in time to satisfy the Government needs. This would then meet the second condition for the definition of a commercial item as described in the FAR definition above and enable the subsequent purchase of services in a follow-on second phase.

In the first phase, NASA decided to take on the role of an investor, technical consultant, and partner instead of a traditional Government customer that pays full development costs and fees to a prime contractor. Since NASA did not intend to purchase any goods or services in the first phase of the program, the C3PO used NASA's other transaction authority in the form of funded Space Act Agreements (SAA) as the optimal legal instrument to provide financial and technical resources to commercial companies.

As the mission of the program became clear, the C3PO established the following three major program objectives: 1) implement Space Exploration policy with investments to stimulate the commercial space industry, 2) facilitate U.S. private industry demonstration of cargo and crew space transportation capabilities with the goal of achieving safe, reliable, cost effective access to low-Earth orbit, and 3) create a market environment where commercial services are available to Government and private sector customers. The vision would extend human presence in space by enabling an expanding and robust U.S. commercial space transportation industry. If successful, NASA's expanded vision and mission to reduce the cost of access to space could open new markets and seed a vibrant and thriving new industry for the long term benefit of all Americans. Of course NASA would also directly benefit by freeing up encumbered resources that could be refocused on the more difficult challenges of human exploration beyond LEO.

After receiving positive and constructive feedback from industry endorsing the proposed new acquisition approach, the C3PO conducted COTS competitions where companies could bid on the development and demonstration on any combination of the following four basic space transportation capabilities to service a human destination in LEO. Capability A: the delivery and disposal on unpressurized/external cargo, B: the delivery and disposal on pressurized/internal cargo, C: the delivery and return of pressurized/internal cargo, and D: crew transportation. In order to fund the maximum number of companies possible with the limited funds available, NASA required the demonstration of cargo capabilities before crew. The crew proposals would become options to the SAA should NASA receive additional funding and elect to exercise the option at some later time. The demonstrations would culminate with an orbital flight demonstration of the selected capabilities. The ISS was offered as a test bed and orbital destination for these capabilities if companies chose to meet the ISS visiting vehicle requirements. In addition to financial payments based on the successful achievement of pre-negotiated milestones, companies awarded SAAs would also receive NASA technical expertise to assist with ISS integration and share knowledge, experience, and lessons learned over our 50 years of human spaceflight.

The resulting funded SAAs represent a new way of doing business with the private sector. The COTS model for public-private partnerships is fundamentally different than traditional Government contracting in many ways. Since the outcome cannot be assured, it has advantages and risks that must be carefully assessed before a determination is made on whether or not this approach is suitable for a specific acquisition.

Features of the COTS Space Act Agreements

Most of the terms and conditions of the COTS SAAs were specially crafted to optimize the commercial development nature of the agreements for the mutual benefit of NASA and the commercial partners. The ability to customize

the agreements for this specific purpose is perhaps the single largest advantage of the SAA. But NASA must first determine that no other legal instrument including, but not limited to; procurement contracts, grants, and cooperative agreements are appropriate for the stated purpose. The primary purpose of the COTS agreements is to stimulate the commercial space industry to develop and demonstrate innovative, cost effective space transportation capabilities. The agreements are for demonstrations and not for the acquisition of goods or services.

The key features and advantages of the COTS SAAs are as follows:

1) Enables a portfolio investment in multiple, diverse commercial partners.

   The *investment* in this context is analogous to the risks versus rewards inherent in any financial portfolio. As in most financial investments, there is no guarantee that a return will be provided, but a diversified portfolio increases the chances of a positive outcome over time. NASA's strategy in COTS was to enable the ability to fund a range of companies including large, established companies representing lower technical risk balanced by small or emerging companies with higher risk. The expectation was that if successful, the higher risk companies could result in a transformational payoff by offering significantly lower service prices. A balanced portfolio would also allow NASA a greater chance to invest in multiple companies since NASA's contribution to the development costs for small companies would likely be less than that required of large businesses. Funding the maximum possible number of companies was a key risk mitigation strategy in COTS since it is common in high risk ventures that only the best and strongest companies will survive and succeed. Companies were selected based on NASA's level of confidence in their ability to meet both the technical goals as well as the execution of their business plan. In contrast, FAR contracts are typically evaluated and scored based on the degree to which companies meet a definitive set of requirements as well as past performance and cost. This would most likely favor companies with lower overall risk and those with a history of doing business with Government.

2) Leverages NASA investment with additional company provided capital.

   The COTS SAAs require that NASA not be the only source of funding necessary to complete the demonstrations. As with most new business ventures, companies typically seek financial investors or approval to apply corporate research and development funds to bring a product to market. NASA learned to think like an investor when soliciting and evaluating the COTS proposals. A successful venture requires a company to have a solid value proposition, a strong business case, and the financial and intellectual capital necessary to be the first to market or capture a share of an existing market. We expected companies to have "skin in the game" in order for us to share the cost risk as a lead investor. The degree to which companies were willing and credibly able to contribute financially to the demonstrations was an important factor in the selection. The selected COTS companies committed several hundred million dollars in addition to NASA's funding which further enabled our ability to invest in multiple companies.

3) Enables known/limited cost risk using pay for performance milestones.

   The COTS SAAs utilize a series of pre-negotiated milestones as the sole basis for performance evaluation and incremental payments. Upon award, NASA agreed to pay up to a fixed maximum amount over the life of the agreement thereby establishing a known and limited financial risk. The SpaceX SAA includes 22 milestones for payments totaling up to $278M. The Orbital SAA includes 19 milestones totaling up to $170M. The milestones measure key progress events throughout the design and development cycle and are typically spaced at least one per quarter. The milestones include a clear and concise description of the event, objective success criteria, and a planned completion date to enable an easy assessment of technical and schedule progress. Payments are made after NASA determines that the milestone was completed in accordance with the established success criteria. This clear and simple payment process avoids subjective cost and fee evaluations and simplifies fiscal year budget planning. More importantly, since NASA's contribution is capped at a pre-negotiated maximum limit, any overrun at any point in the project becomes the responsibility of the commercial partner. NASA's milestone payments remain fixed regardless of the actual costs incurred by the company. Regarding schedule delays, the milestones were initially defined as events only but completion dates were added during negotiations so a planning baseline could be established. According to the terms of the SAA, once a milestone is missed, NASA must ascertain the cause of the failure and determine if additional efforts are in the Government's best interest. Delays in completing the milestones are not sufficient cause for termination as long as NASA determines that

reasonable progress is being made. It should also be noted that NASA recognized the schedules proposed by the COTS partners were extremely aggressive and delays would be expected.

4) Mitigates cost impacts due to evolving requirements.

   One of the most elegant features of a funded SAA partnership in a design and development environment is that the system requirements are permitted to evolve and mature without the constant administration of contract change orders and equitable adjustments. Since NASA only provided top level system performance goals and objectives, representative of one customer's needs for such services, this allowed companies to freely innovate and optimize their system throughout the design cycle. Instead of constantly evaluating and independently analyzing system performance against detailed design requirements and specifications NASA typically applies on a contract, NASA monitors the progress of the design to assure that the system is being built and tested in accordance with the original scope of the agreement. Even the ISS safety and interface requirements have evolved over time with mutual agreement. Since the inception of the SAAs, NASA has processed over 70 changes to the COTS Interface Requirements Document (IRD) without a single dollar of equitable adjustment. The reason for this is commercial companies *volunteered* to meet the IRD in their COTS proposal. The ISS was offered, but not required to be used as the orbital flight destination. Companies serious about producing a transportation system with NASA as a reliable customer took on the challenge of meeting the ISS requirements for the best possible opportunity to be awarded a lucrative service contract. Also over these last four years, the SAAs were only modified six times to document mutually agreeable content changes, again without any adjustment in total payments. It is highly doubtful that NASA would be able to achieve the flexibility of implementing these type changes without cost adjustments under a contract.

5) Enables streamlined/flexible acquisition process.

   Government acquisitions under the FAR are designed to assure federal funds are awarded fairly and are disbursed in strict accordance with a contract terms and conditions. The regulations typically require contracts to contain certain standard clauses regarding specific reporting requirements and deliverables, systems to validate contractor costs, and other paperwork and processes to provide the necessary and appropriate controls on such a massive system. NASA is one of the few organizations in the Government granted other transaction authority to enter into agreements outside the FAR. If and only when no other instrument is deemed appropriate, NASA can utilize this authority to carry out its mission. Because the use of SAAs was deemed most appropriate for COTS partnerships, this has allowed NASA to streamline the acquisition and execution process. Reducing some of the so called "red tape" and other requirements for doing business with the Government has leveled the playing field. The COTS competitions were structured such that large, established companies with a long history of Government contracts could compete equally and fairly with small, even startup emerging companies who have little or no experience with Government acquisitions. For example, instead of evaluating a company's past performance on similar work, NASA focused on the skills and demonstrated abilities of the management team proposed to lead the effort. While still assuring federal funds are awarded fairly and are disbursed under strict control, the flexibility of the SAAs enabled each step of the process to be specially tailored. This resulted in decreased overhead costs to both the Government and the commercial partner and a streamlined acquisition schedule.

6) Simplifies program management/oversight with objective milestone success criteria.

   Because the milestones listed in the SAAs are the sole basis for monitoring progress and making payments to the commercial partner, this greatly simplifies and streamlines program management. The C3PO employs only 14 direct and matrixed personnel to oversee and manage the two COTS SAAs and five recently awarded Commercial Crew Development SAAs which also used the COTS model. These include program / project managers and deputies, program integration, safety, procurement, financial, and administrative personnel. Additional insight is gained during informal day to day communications with the partners as well as more formal quarterly program management reviews, but the official basis for assessing progress and making payments are the SAA milestones. The milestones form the basis for NASA's limited program oversight responsibilities. The program also budgets for approximately 10 additional FTE to provide specific technical expertise as needed from the NASA centers and procured program technical support.

7) Minimum requirements encourage innovation and enables reduced/appropriate level of NASA oversight/insight.

NASA holds ourselves accountable for the validation and verification of each and every requirement we impose on our contractors. Many thousands of requirements are typically invoked on any complex space system development. Ultimately, NASA certifies that the requirements have been met to our satisfaction and the system is ready for its mission. This system of checks and balances provides us with the highest assurance of mission success but at the expense of a large workforce, cost, and schedule. Indeed it is this experience and expertise behind each of our requirements that make up the incredible workforce NASA employs today. The COTS model seeks to minimize the firm system performance requirements leaving the commercial partner responsible for the flow down and verification of most all requirements. By sharing our needs as a primary, but not necessarily the only customer early on, commercial partners are free to optimize their systems to best fit their business case. Because the level of insight is driven by our mutual goal of helping the partnership succeed, NASA is able to closely manage and prioritize the level of technical support we provide. The ISS safety and interface requirements are an exception to this approach. The closure of ISS requirements requires close oversight and must be verified by NASA to the same extent as any of our other contracted requirements. Even so, ISS requirements number into the hundreds, not thousands and NASA is able to accomplish the necessary oversight function with a much smaller number of people.

8) Maximizes incentive to hold cost and schedule.

   Since COTS payments are made only after the successful completion of a defined milestone, companies are required to raise the capital necessary to accomplish the work up front. This approach builds in an automatic incentive for companies to complete the effort on or under cost and as soon as possible so they can be reimbursed and move forward to the next milestone. COTS companies are also highly incentivized to hold cost and schedule because of our strategy to invest in multiple companies. This engages the engine of competition where companies strive to offer the best value and capture a share of existing markets or create new markets as soon as possible.

9) Commercial friendly intellectual/physical property and data rights.

   The COTS SAAs include special provisions for minimal Government retention, licensing, and use of intellectual property developed by companies under the agreements. Similarly, the Government will not take title to property acquired or developed using funding provided under the agreement. These provisions assure companies will retain the benefit of their investment and further encourages the development of the commercial space industry. If however, the agreements are terminated for failure to perform, NASA may exercise all rights to property and data.

10) Limited termination liability.

   Unlike most contracts, NASA may not unilaterally terminate the agreements for the convenience of the Government. In other words NASA cannot walk away from the agreement except for reasons that are beyond our control (such as failure of Congress to appropriate sufficient funding). Likewise, the commercial partners are obligated to meet the terms and conditions of the agreements or they will be terminated for failure to perform. If the Government is forced to unilaterally terminate, the maximum financial liability shall not exceed the total amount of the next milestone. The agreements also allow for mutual agreement to terminate if ever needed. These limited termination provisions were found to be very important and advantageous to companies seeking additional outside investments.

11) FAA licensing/liability/indemnification/enforcement.

   The COTS flight demonstrations are not NASA missions carried out by and for the Government and therefore fall under the FAA licensing regulations. The FAA is directed by law to encourage and promote entrepreneurial space activity and is further directed to simplify and expedite the issuance of licenses. This determination relieves NASA from conducting our launch oversight of these missions and prepares the companies for follow-on commercial space transportation services under the FAA regulations.

Lessons Learned

1) In October 2007, NASA terminated its $207 million SAA with Rocketplane Kistler (RpK) for failure to meet milestones just over a year after award. RpK committed to raise an additional $500 million in order to complete the development and demonstration of its K1 reusable launch vehicle but was unable to close the necessary rounds of financing. NASA recognized the risk associated with raising this large amount of capital and purposely limited the initial milestones until the funding was secured. RpK completed the first three milestones

and received $32 million in payments. As the program was designed to do, the termination was conducted swiftly resulting in minimum financial and schedule loss. Within four months, NASA conducted a second round competition and awarded the remaining $170 million to Orbital Sciences Corporation.

RpK informed NASA that the primary reason they were unable to complete the financing was because NASA could not guarantee or even commit to the follow-on ISS resupply service contract. Investors in the financial markets were simply not willing to take on this high risk venture without an assured return on investment. They recognized NASA was the only reliable customer for these services since other markets have had limited development and have yet to materialize. This concern was expressed by most companies seeking outside or corporate investment when NASA received RFI responses from industry in preparation for the ISS Commercial Resupply Services contracts.

Therefore, given that the requirement for additional company investment is an important part of this form of partnership, NASA should not expect companies to raise funds from financial markets unless we are willing to commit to purchase their services. The transition from development partnerships to operational service contracts is important to any future acquisition planning using this approach. NASA should consider ways to assure selected partners will be offered follow-on contracts if they are successful in demonstrating their capabilities.

2) Another lesson learned from COTS is that NASA does not have the statutory authority to provide Government Furnished Equipment (GFE) under the SAA. Even though GFE for certain rendezvous and proximity operations equipment was contemplated in the original agreements, transferring this equipment has been problematic. Conversely, NASA also does not have the authority to receive deliverables from the partner under the SAA. For example, NASA was unable to accept additional UHF Communications Units developed by SpaceX for ISS proximity communications with commercial spacecraft. The additional units were to be provided in exchange for other associated NASA services and could have been used for the Orion project or perhaps other visiting vehicles.

   Therefore, NASA should clearly identify and list the hardware and software deliverables that are necessary to be exchanged prior to signing the initial agreement. Alternatively, NASA should seek legislation or determine an appropriate legal way to accommodate such equipment transfers under a SAA.

3) NASA saw significant growth in service prices from those projected in the COTS proposals to those finally negotiated in the CRS contracts. Some of the growth may be due to additional requirements in the contracts. Another factor may be that the systems were matured since the initial proposals and the pricing was more accurately reflective of the actual costs incurred and projected costs to complete. Since the prices projected in the COTS proposals were not binding, future evaluation teams should consider the large uncertainty range in these prices if they are used as part of the selection criteria. Also, NASA should carefully plan the point in the development cycle when a Request for Proposals for service contracts is issued. Ideally, NASA should wait until the capability is demonstrated, but this would likely result in an 18-24 month gap before an operational mission is flown due to vehicle production lead time. Conversely, issuing RFPs too early will lead to inaccurate price projections and perhaps schedule delays and penalties due to unexpected development issues.

Summary

The COTS model for public-private partnerships has paved the way for the procurement of commercial space transportation services. What started as an unknown experiment four years ago has resulted in a new medium class launch vehicle poised to launch in the days ahead, another under construction and soon ready for test, and a sure promise of two highly advanced cargo carrying spacecraft planned to visit the space station in the year ahead. This was made possible because NASA was willing to risk $500 million as a bold lead investor confident in its commercial partners. This strategic investment was significant enough to break through the barriers to entry in this extremely difficult and risky business, yet modest enough to be affordable and fiscally responsible. NASA knows all too well there will be failures and setbacks ahead. But we also know that through the trusted partnerships we have forged with our industry colleagues, problems will be solved and a new era in commercial space will begin.

Chronology

1800s – 1900s

1863 – 1869	Construction of the First Transcontinental Railroad
1925	Contract Air Mail Act (Kelly Act)
1958	NASA founded Federal Aviation Administration (FAA) founded

1970s and 1980s

1979	First Joint Endeavor Agreement
4/12/1981	First Space Shuttle launch (STS-1)
1982	Reagan's National Space Policy
4/1982	Orbital Sciences Corp. founded
9/1984	NASA Office of Commercial Programs established
10/30/1984	Commercial Space Launch Act
1/28/1986	*Challenger* disaster
8/15/1986	Commercial payloads banned from Shuttle

1990s

11/5/1990	Launch Services Purchase Act
1993	Kistler Aerospace Corp. founded
2/1995	Report of the Space Shuttle Management Independent Review Team (Kraft Report)
10/28/1998	Commercial Space Act of 1998
6/1999	Decadal Planning Team formed

2000s

2001 – 2002	Space Launch Initiative (SLI)
	Alternate Access to Space Station (AAS)
2002	SpaceX founded
2/1/2003	*Columbia* disaster
1/14/2004	Vision for Space Exploration announced
9/2004	Concept Exploration & Refinement Studies
10/4/2004	Ansari X Prize awarded
12/23/2004	Commercial Space Launch Amendments Act

2005

4/25/2005	ISS Commercial Cargo Services Industry Day
10/5/2005	First COTS "kickoff" meeting
10/28/2005	COTS Space Flight Demonstrations synopsis released
11/2005	Commercial Crew & Cargo Program Office established at JSC
	Exploration Systems Architecture Study (ESAS) Final Report
12/5/2005	COTS Draft Announcement released
12/21/2005	JSC Request for Proposal for Venture Capitalist Consulting Services

2006

1/18/2006	COTS Round 1 Announcement released
1/25/2006	COTS ISS Integration & Interface Requirements Document released
3/3/2006	COTS Round 1 proposals due
5/5/2006	COTS Round 1 finalists selected
7/14/2006	COTS Round 1 negotiations completed
8/18/2006	Space Act Agreements signed with SpaceX and Rocketplane Kistler
12/19/2006	COTS Round 1 GAO protest successfully defended

2007

1/2007 and 6/2007	Unfunded Space Act Agreements signed
10/18/2007	Rocketplane Kistler Space Act Agreement terminated
10/22/2007	COTS Round 2 Announcement released
11/22/2007	COTS Round 2 proposals due

2008

1/28/2008	COTS Round 2 GAO protest successfully defended
2/19/2008	Space Act Agreement signed with Orbital Sciences Corp.
5/2008 – 10/2008	Unfunded Space Act Agreements terminated
9/28/2008	First launch of the SpaceX Falcon 1 rocket
12/23/2008	Commercial Resupply Service (CRS) contracts awarded

2009

4/22/2009	CRS protest successfully defended
8/10/2009	Commercial Crew Development (CCDev) Announcement released
9/22/2009	CCDev proposals due
10/2009	Report of the Review of United States Human Spaceflight Plans Committee (Augustine Commission)
12/8/2009	CCDev selection

2010

2/2010	Constellation Program cancelled
6/4/2010	First launch of the SpaceX Falcon 9 rocket
10/11/2010	NASA Authorization Act of 2010 allocated $300 million COTS augmentation funding
12/8/2010	SpaceX C1 demonstration mission

2012

5/22/2012 – 5/31/2012	SpaceX C2+ final COTS demonstration mission
10/8/2012 – 10/28/2012	First SpaceX Cargo Resupply Services mission

2013

4/21/2013	Orbital Sciences Corp. Antares rocket demonstration flight
9/18/2013 – 10/23/2013	Orbital Sciences Corp. final COTS demonstration mission

2014

1/9/2014 – 2/19/2014	First Orbital Sciences Corp. Cargo Resupply Services mission

SpaceX COTS Milestones

	Milestones	$M	$M Total	2006 Q3	2006 Q4	2007 Q1	2007 Q2	2007 Q3	2007 Q4	2008 Q1	2008 Q2	2008 Q3	2008 Q4	2009 Q1	2009 Q2	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4
		278.0																										
1	Project Mgmt Plan	23.1	23.1	Sep 15																								
2	Demo 1 SRR	5.0	28.1		Nov 29																							
3	Demo 1 PDR	18.1	46.2			Feb 8																						
4	Financing Round 1	10.0	56.2			Mar 1																						
5	Demo 2 SRR	31.1	87.4			Mar 15																						
6	Demo 1 CDR	8.1	95.5				Aug 22																					
7	Demo 3 SRR	22.3	117.8				Oct 29																					
8	Demo 2 PDR	21.1	139.0						Dec 19																			
9	Draco Init. Hot fire	6.0	145.0							Mar 21																		
10	Financing Round 2	10.0	155.0							Mar 21																		
11	Demo 3 PDR	22.0	177.0							Apr	Jun 27																	
12	Multi-Engine Test	22.0	199.0								Aug 4	Sep																
13	Demo 2/3 CDR	25.0	224.0									Dec 18	Jan															
14	Financing Round 3	10.0	234.0									Feb 8	Mar															
15	Demo 1 RR	5.0	239.0							Feb			Mar				Jun 8											
16	CUCU Flight Unit	9.0	248.0										May	Jul 23														
17	Demo 1 Mission	5.0	253.0								Sep		Jun				Dec 15											
18	Demo 2 RR	5.0	258.0									Dec									Sep			Mar 9				
19	Demo 2 Mission	5.0	263.0										Jun								Nov			Jun 7				
20	Cargo Int. Demo	5.0	268.0											Dec 18	Jan													
21	Demo 3 RR	5.0	273.0											Jul										Dec		Aug 22		
22	Demo 3 Mission	5.0	278.0											Sep										Jan		Jun 7		

SpaceX Augmented COTS Milestones

	Milestones	$M	$M Total	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4
		118.0											
23	Modal Test Plan	5.0	5.0	Dec 16									
24	Modal Test	5.0	10.0	Dec 16									
25	LIDAR Test (open loop)	5.0	15.0	Dec 16									
26	Solar Array Deploy Test	5.0	20.0	Dec 16									
27	LIDAR Test Plan (closed loop)	5.0	25.0			Mar 31							
28	Thermal Vacuum Test Plan	5.0	30.0			Mar	Apr 6						
29	Infrastructure Plan	10.0	40.0			Mar	May 10						
30	Thermal Vacuum Test	20.0	60.0				Jul	Sep 14					
31	Test site Infrastructure Implementation	5.0	65.0				Jun 23						
32	Dragon Trunk Acoustic Test	10.0	75.0				Jun 23						
33	LIDAR Test 6 DOF (closed loop)	5.0	80.0				Aug	Oct 26					
34	Design Rev. Enhanced Powered Cargo Accom.	5.0	85.0				Aug 24						
35	Design Rev. Pressurized Cargo Vol Increase	5.0	90.0				Aug 24						
36	Dragon EMI/EMC Test (HITL)	10.0	100.0				Jul	Sep 20					
37	Dragon Cargo Racks & Hatch Simulator	3.0	103.0				Aug 26						
38	Ground Demo Enhanced Powered Cargo	5.0	108.0				Sep	Oct 26					
39	Launch site Infrastructure Implementation	5.0	113.0				Sep	Oct 26					
40	Production Infrastructure Implementation	5.0	118.0				Sep	Oct 26					
	SAA Total	**396.0**	**396.0**										

Amended SAA Plan

Initial SAA Plan

Actual Completion Date*

** Actual Completion Date is when NASA verified that the partner completed the milestone.*

Orbital COTS Milestones

	Milestones	$M	$M Total	2008 Q1	2008 Q2	2008 Q3	2008 Q4	2009 Q1	2009 Q2	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4	2013 Q1	2013 Q2	2013 Q3	2013 Q4
		170.0																							
1	Program Plan Review	10.0	10.0	Mar 31																					
2	Demo Mission SRR	20.0	30.0	Jun		Jul 17																			
3	UCM PDR	10.0	40.0		Jul		Aug 14																		
4	DELETED																								
5	COTS Int/Ops Facility	10.0	50.0		Sep 22		Oct																		
6	PCM PDR	10.0	60.0			Oct 9	Nov																		
7	DELETED																								
8	IP&CL Submission	10.0	70.0					Feb 18																	
9	ISS Phase 1 SRP	10.0	80.0					Mar 27																	
10	COTS System PDR	20.0	100.0			Sep		Apr	May 22																
11	PCM CDR	10.0	110.0						Jul 31																
12	Cygnus Avionics Test	10.0	120.0					Jun	Aug 13																
13	ISS Phase 2 SRP	10.0	130.0						Aug	Nov 6															
14	COTS System CDR	10.0	140.0					Mar	Sep	Mar 23															
15	SM Core Assembly Complete	7.5	147.5						Oct	Dec	Aug 30														
16	SM Test Readines Review	7.5	155.0							Jan	Apr	Nov 17													
17	SM Initial CPT	5.0	160.0								May	Jun	Dec 14												
18	LV Stage I Assy. Complete	2.5	162.5									Sep	Sep	Jul 11											
19	Cargo Int. Demo	2.5	165.0										Dec 6												
20	Mission Readiness Review	2.5	167.5									Oct	Oct	Jul 27											
21	System Demo Flight	2.5	170.0									Dec	Dec	Nov 7											

Orbital Augmented COTS Milestones

		118.0		
22	Test Flight Mission Review	20.0	190.0	Dec 15
23	Test Flight Mission Analys.	10.0	200.0	Feb 23
24	Cygnus Mass Sim. (CMS) Design Review	10.0	210.0	Mar 03
25	Install Add'l PITL Simulators	5.0	215.0	Apr May 6
26	PROX FEU Test Unit	5.0	220.0	May Jun 17
27	Maiden Flt Stg 1 Core Del.	24.0	244.0	Apr 28
28	Maiden Flt Uppr Stage Del.	20.0	264.0	Jun 21
29	Maiden Flt CMS Delivered	10.0	274.0	Jun 20
30	Maiden Flt Stage 1 Assy.	10.0	284.0	Jul Sep 17
31	Maiden Test Flight	4.0	288.0	Oct May 9
	SAA Total	**288.0**	**288.0**	

Amended SAA Plan

Initial SAA Plan

Actual Completion Date*

** Actual Completion Date is when NASA verified that the partner completed the milestone.*

COTS Oral History Interviews

The NASA Johnson Space Center History Office conducted a series of oral history interviews to gather information from key individuals involved with the Commercial Crew & Cargo Program. Interviews were conducted by Rebecca Hackler and Rebecca Wright. To access the transcripts from the interview sessions, go to the JSC History Portal, *http://www.jsc.nasa.gov/history/oral_histories/c3po.htm*.

NASA

Lori Garver	NASA Deputy Administrator
Bill Gerstenmaier	NASA Associate Administrator, Human Exploration and Operations
Marc Timm	NASA HQ COTS Program Executive
Alan Lindenmoyer	C3PO Manager
Valin Thorn	C3PO Deputy Program Manager
Dennis Stone	C3PO Program Integration Manager
Mike Horkachuck	C3PO Project Executive – SpaceX
Bruce Manners	C3PO Project Executive – RpK, Orbital Sciences
Lisa Price	COTS Financial Team
Kathy Lueders	Manager, ISS Program Transportation Integration Office
HQ Legal Team	Mike Wholley, NASA Chief Counsel
	Sumara Thompson-King, Deputy General Counsel
	Courtney Graham, Associate General Counsel for Commercial and Intellectual Property Law
	Karen Reilley, Attorney, Contracts and Procurement
Amy Xenofos	Chief Counsel for General Law and External Partnerships, Johnson Space Center
Jon Arena	Counsel, Johnson Space Center

Others

Mike Griffin	NASA Administrator, April 2005 - January 2009
Alan Marty	Venture Capitalist, Managing Director, Legacy Venture
George Nield	Federal Aviation Administration Associate Administrator for Commercial Space Transportation
Brett Alexander	Blue Origin, Business Development/Strategy
Jim Muncy	President, PoliSpace, co-founder Space Frontier Foundation

SpaceX

Gwynne Shotwell	President, Chief Operating Officer
Hans Koenigsmann	Vice President of Mission Assurance
Tim Buzza	Vice President of Launch and Test
David Giger	Director, Dragon Propulsion and Product Development
John Couluris	Senior Director, Launch and Mission Operations
Peter Capozzoli	Mission Manager

Rocketplane Kistler

Randy Brinkley	President
Joe Cuzzupoli	Chief Engineer
George French	Chief Executive Officer

Orbital Sciences Corp.

David Thompson	President, Chairman, Chief Executive Officer
Antonio Elias	Executive Vice President and Chief Technical Officer
Frank Culbertson	Executive Vice President and General Manager Advance Programs Group
Bob Richards	Vice President of Human Spaceflight Systems
Frank DeMauro	Vice President and Program Director COTS/CRS Program (Cygnus)
Mike Pinkston & Kurt Eberly	Antares Space Launch Vehicle, Managers

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91 Joint Sponsored Research Agreements had been used in the past to provide funding to outside entities under NASA's OTA, but COTS was the first time funded Space Act Agreements had been established as such. NASA Headquarters attorney Courtney B. Graham explained that under COTS, the Agency was "acting as an arm's-length investor to stimulate the development of that capability, rather than working jointly with someone on something that's of mutual interest to both parties." Thompson-King, Graham, and Reilley, interview.

92 *Oral History Workshop: Commercial Space Policies of the 1980s,* moderated by Woody Kay, November 1, 1999, transcript, NASA Headquarters Historical Reference Collection, Washington, DC.

93 Dennis A. Stone, interview by Rebecca Hackler, November 26, 2012, transcript, C3PO OHP.

94 NASA JSC Solicitation: Venture Capitalist Consulting Services, Solicitation Number: NNJ06139211R, posted December 21, 2005, accessed September 30, 2013, *http://www.spaceref.com/news/viewsr.html?pid=19046.*

95 Alan Marty, interview by Rebecca Hackler, January 18, 2013, transcript, C3PO OHP.

96 The book's first edition was published by the Harvard School Business Press in 1997 as *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. For the edition referenced in this work see Clayton M. Christensen, *The Innovator's Dilemma: The Revolutionary Book That Will Change the Way You Do Business* (New York: Harper Business, 2011).

97 Marty reported that his original recommendation to Griffin, as they discussed the initiative during an informal conversation at a White House dinner, was to base the COTS program out of the NASA Ames Research Center in Moffett Field, California, to remove the program as far as possible from the Agency's traditional human spaceflight culture. However, by that point an office had already been established at JSC. Marty, interview.

98 Marty, interview; Lindenmoyer, interview.

99 Marty, interview.

100 Michael D. Griffin, interview by Rebecca Wright, January 12, 2013, transcript, C3PO OHP.

101 Marty, interview. See also Lindenmoyer, interview.

102 Bruce A. Manners, interview by Rebecca Hackler, December 5, 2013, transcript, C3PO OHP; Dennis Stone, email communication to JSC History Office, July 21, 2013.

103 Marty, interview. Around the same time as the first COTS award, in September 2006, NASA founded its own venture capital firm, Red Planet Capital, to invest in companies that were developing technologies that could be of use in NASA's future missions to Mars. The project was shut down less than a year later due to concerns about the government competing with the private sector. "NASA Forms Partnership with Red Planet Capital, Inc.," NASA News Release 06-317, September 20, 2006, accessed September 30, 3013, *http://www.nasa.gov/home/hqnews/2006/sep/HQ_06317_red_capital.html*; Marc Kaufman, "NASA Invests in Its Future With Venture Capital Firm," *Washington Post,* October 31, 2006, accessed September 30, 2013, *http://www.washingtonpost.com/wp-dyn/content/article/2006/10/30/AR2006103001069.html*. See also Marty, interview and Thompson-King, Graham, and Reilley, interview.

104 National Aeronautics and Space Administration Authorization Act of 1985, Public Law 98–361, 98th Cong., 2d sess. (July 16, 1984), §110(c), accessed September 30, 2013, *http://uscodebeta.house.gov/statutes/1984/1984-098-0361.pdf*. In 2010 the Space Act was amended so that this phrasing was now found in §20102(c). National Aeronautics and Space Act, Public Law 111–314, 111th Cong., 2d sess. (December 18, 2010), accessed September 30, 2013, *http://www.gpo.gov/fdsys/pkg/BILLS-111hr3237enr/pdf/BILLS-111hr3237enr.pdf*.

105 COTS Announcement, COTS-01-05.

106 Ibid., Also Timm, interview. Joan Lisa Bromberg noted that in traditional contract procurements "arrogant" proposals, i.e., those that did not strictly conform to government-defined Request for Proposal requirements, often resulted in greater creativity. Joan Lisa Bromberg, *NASA and the Space Industry* (Baltimore: John Hopkins University Press, 1999), 43.

107 Lindenmoyer, interview.

108 COTS Announcement, COTS-01-05, A21.

109 Marty, interview.

110 According to NASA attorney Amy V. Xenofos, one company did in fact propose to, instead of visiting the ISS, launch a spent stage to orbit and then dock with it in order to demonstrate its low-Earth orbit capabilities. Xenofos, interview. See also Manners, interview.

111 COTS Announcement, COTS-01-05, 19.

112 "Valin Thorn, Deputy Manager," NASA Commercial Crew & Cargo Program Office, last modified August 17, 2011, accessed September 30, 2013, *http://www.nasa.gov/offices/c3po/about/vthorn.html*; Thorn, interview.

113 Valin Thorn, Neil Lemmons, and Matt Scheutz, "ISS Commercial Cargo Service: Requirements & Constraints Summary" (PowerPoint presentation at ISS Commercial Cargo Service Industry Day Conference, Houston, TX, April 25, 2005), accessed September 30, 2013, *http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20060055384_2006256513.pdf*.

114 Thorn, interview.

115 Commercial Orbital Transportation Service: ISS Integration & Interface Requirements Document, SSP 50784, Version 1.0, January 25, 2006, 15, Commercial Crew & Cargo Program Office, Houston, TX.

116 Lindenmoyer, interview.

Chapter 3

117 Commercial Orbital Transportation Services (COTS) Demonstrations, Announcement Number COTS-01-05, Commercial Crew/Cargo Project Office, January 18, 2006 (As Amended February 17, 2006), accessed September 30, 2013, available at *http://www.nasa.gov/offices/c3po/about/cots_demo_competition.html*. The amendments released in February were fairly minor, consisting of clarifications regarding instructions for electronic proposal submittal (§5.1.3 and §5.1.5) and the use of government-furnished equipment (Appendix B).

118 COTS Announcement, COTS-01-05, 8-9. The requirement for U.S. funding would prove to be one of the factors in RpK's failed quest to meet its financial milestones.

119 At the time of the announcement, the Iran and Syria Nonproliferation Act prohibited payments to Russia for ISS-related services after December 2011; on 14 January 2013, Congress extended NASA's waiver from the Iran North Korea and Syria Nonproliferation Act (INKSNA), allowing the Agency to purchase ISS services from Russia through 2020. Space Exploration Sustainability Act, Public Law 112-273, 112th Congress, 2d sess. (January 14, 2013), §4, accessed September 30, 2013, *http://www.gpo.gov/fdsys/pkg/PLAW-112publ273/pdf/PLAW-112publ273.pdf*.

120 Dennis Stone, email communication to JSC History Office, July 15, 2013.

121 Valin B. Thorn, interview by Rebecca Hackler, December 17, 2012, transcript, Commercial Crew & Cargo Program Office History Project, JSC History Collection, University of Houston-Clear Lake, Houston, TX (hereafter cited as C3PO OHP); Bruce A. Manners, interview by Rebecca Hackler, December 5, 2013, transcript, C3PO OHP.

122 Amy V. Xenofos, interview by Rebecca Hackler, December 7, 2012, transcript, C3PO OHP.

123 Dennis Stone, email communication to JSC History Office, July 15, 2013.

124 Thorn, interview. See also Joan Lisa Bromberg, *NASA and the Space Industry* (Baltimore: John Hopkins University Press, 1999), 7.

125 Participant Evaluation Plan, Commercial Orbital Transportation Services Demonstrations, Announcement Number COTS-01-05, 5-6, Commercial Crew & Cargo Program Office, Houston, TX.

126 Participant Evaluation Plan, 11. See also Dennis A. Stone, interview by Rebecca Hackler, November 26, 2012, transcript, C3PO OHP.

127 "COTS 2006 Demo Competition," Commercial Crew & Cargo Program Office, last updated March 2, 2012, accessed November 21, 2013, *http://www.nasa.gov/offices/c3po/about/cots_demo_competition.html*.

128 Scott J. Horowitz, interview by Rebecca Wright, March 1, 2013, transcript, JSC Oral History Project, JSC History Collection, University of Houston-Clear Lake, Houston, TX. See also Michael C. Wholley, interview by Rebecca Hackler, March 19, 2013, transcript, C3PO OHP.

129 Jeff Foust, "Small Steps Forward for NewSpace," *The Space Review,* April 24, 2006, accessed September 30, 2013, *http://www.thespacereview.com/article/609/1*.

130 Participant Evaluation Plan, 8.

131 Ibid., 9; Scott J. Horowitz, Commercial Orbital Transportation Services (COTS) Final Selection Statement, August 18, 2006, Attachment A, Commercial Crew & Cargo Program Office, Houston, TX.

132 Alan J. Lindenmoyer, interview by Rebecca Wright, October 31, 2012, transcript, C3PO OHP.

133 Participant Evaluation Plan, 17. See also Lindenmoyer, interview.

134 Horowitz, Final Selection Statement, 1; Alan Marty, interview by Rebecca Hackler, January 18, 2013, transcript, C3PO OHP.

135 Dennis Stone, email communication to JSC History Office, July 15, 2013.

136 Participant Evaluation Plan, 22.

137 Ibid., 17.

138 NASA Administrator Michael Griffin later expressed surprise that some major aerospace contractors failed to submit competitive proposals. Those that did submit proposals requested more than the available NASA funding. Michael D. Griffin, interview by Rebecca Wright, January 12, 2013, transcript, C3PO OHP. See also Wholley, interview. Economist Clayton M. Christensen observed that small markets—such as the relatively insignificant $500 million COTS funding—do not provide enough growth opportunities for large companies. In other words, "an opportunity that excites a small organization isn't large enough to be interesting to a very large one. One of the bittersweet rewards of success is that as companies become large, they lose the capability to enter small emerging markets." Clayton M. Christensen, *The Innovator's Dilemma: The Revolutionary Book That Will Change the Way You Do Business* (New York: Harper Business, 2011), 190.

139 Stone, interview. See also Jonathan A. Arena, interview by Rebecca Hackler, April 22, 2013, transcript, C3PO OHP.

140 Xenofos, interview; Sumara M. Thompson-King, Courtney B. Graham, and Karen M. Reilley, interview by Rebecca Hackler, March 19, 2013, transcript, C3PO OHP.

141 In the case of SpaceHab, Inc., however, the level of confidence rating actually decreased after the face-to-face due diligence meetings. Horowitz, Final Selection Statement, Attachment B.

142 Marc G. Timm, interview by Rebecca Wright, June 12, 2013, transcript, C3PO OHP.

143 Horowitz, Final Selection Statement, 4-5.

144 Ibid.

145 Dennis Stone, email communication to JSC History Office, July 15, 2013.

146 Horowitz, interview.

147 Horowitz, Final Selection Statement, 5. This was true despite the fact that RpK, like SpaceX, proposed the development of all four capabilities and SpaceDev proposed only C and D.

148 The Space Act Agreements of all three of NASA's COTS commercial partners are available online. "Commercial Orbital Transportation Services Demonstration (COTS)," JSC Library, accessed September 30, 2013, *http://www.nasa.gov/centers/johnson/news/contracts/cots.html*.

149 Lindenmoyer, interview; Thorn, interview.

150 Government Accountability Office, *Decision, Matter of: Exploration Partners, LLC,* B-298804, December 19, 2006, accessed September 30, 2013, *http://www.gao.gov/assets/380/378416.pdf*.

151 Xenofos, interview.

152 Ibid.; Thompson-King, Graham, and Reilley, interview; Arena, interview.

153 Thompson-King, Graham, and Reilley, interview.

154 Arena, interview.

155 Alan J. Lindenmoyer, interview by Rebecca Wright, November 7, 2012, transcript, C3PO OHP. See also Manners, interview.

156 Stone, interview. In the words of NASA General Counsel Mike Wholley, "It was well begun as first done." Wholley, interview.

157 Commercial Orbital Transportation Services, Phase 1 Demonstrations, Announcement Number JSC-COTS-2, Commercial Crew & Cargo Program Office, October 22, 2007, accessed September 30, 2013, available at *http://www.nasa.gov/offices/c3po/about/cots_demo_competition_2007.html*. Emphasis added. Also Xenofos, interview. While the Round 1 Announcement (COTS-01-05) stated that "NASA intends to use its Space Act authority to enter into at least one and *preferably* multiple funded agreements," the Round 2 Announcement stated, "NASA intends to use its Space Act authority to enter into at least one and *potentially* multiple funded agreements."

158 COTS Announcement, JSC-COTS-2, 18–19.

159 Xenofos, interview.

160 Douglas R. Cooke, Selection Statement for the Commercial Orbital Transportation Services Phase 1 Demonstrations (Announcement Number JSC-COTS-2), February 15, 2008, 3, Commercial Crew & Cargo Program Office, Houston, TX.

161 Cooke, Selection Statement, 11.

162 Ibid.

163 Antonio L. Elias, interview by Rebecca Hackler, June 3, 2013, transcript, C3PO OHP.

164 Cooke, Selection Statement, 12.

165 Manners, interview.

166 Government Accountability Office, *Decision, Matter of: Rocketplane Kistler,* B-310741, January 28, 2008, 3, accessed September 30, 2013, *http://www.gao.gov/assets/390/381890.pdf*.

167 Ibid., 5. See also Xenofos, interview and Thompson-King, Graham, and Reilley, interview.

168 See Brian Berger, "NASA Signs Space Act Agreements with Three More Firms," *Space.com,* June 19, 2007, accessed September 30, 2013, *http://www.space.com/3975-nasa-signs-space-act-agreements-firms.html*.

169 Thompson-King, Graham, and Reilley, interview.

170 Arena, interview. See also Xenofos, interview.

171 Thompson-King, Graham, and Reilley, interview. See also Arena, interview.

172 Arena, interview; Stone, interview.

173 Cooke, Selection Statement.

174 Thomas B. Pickens III (CEO of SpaceHab, Inc.) to Alan Lindenmoyer, May 29, 2008, Commercial Crew & Cargo Program Office, Houston, TX.

175 Charles Miller (President and CEO of Constellation Services International, Inc.) to Alan Lindenmoyer, July 15, 2008, Commercial Crew & Cargo Program Office, Houston, TX.

176 Charles Duelfer (CEO of the Transformational Space Corp.) to Alan Lindenmoyer, October 16, 2008, Commercial Crew & Cargo Program Office, Houston, TX.

Chapter 4

177 Scott J. Horowitz, Program Formulation Authorization Document, Commercial Crew & Cargo Program, 3, August 14, 2006, Commercial Crew & Cargo Program Office, Houston, TX.

178 The SAA between NASA and SpaceX also included an option for COTS Capability D, a Crewed Vehicle Demonstration valued at $308 million, that was never activated. Space Act Agreement between NASA and SpaceX for Commercial Orbital Transportation Services Demonstration, Appendix 1: Executive Summary, 3, accessed September 30, 2013, *http://www.nasa.gov/centers/johnson/pdf/189228main_setc_nnj06ta26a.pdf*.

179 Lisa P. Price, email communication to JSC History Office, September 19, 2013. See also Consolidated Appropriations Act, 2008, Public Law 110–161, 110th Cong., 1st sess. (December 26, 2007), accessed September 30, 2013, *http://www.gpo.gov/fdsys/pkg/PLAW-110publ161/pdf/PLAW-110publ161.pdf*.

180 Alan J. Lindenmoyer, interview by Rebecca Wright, October 31, 2012, transcript, Commercial Crew & Cargo Program Office History Project, JSC History Collection, University of Houston-Clear Lake, Houston, TX (hereafter cited as C3PO OHP). See also Lisa P. Price, interview by Rebecca Hackler, May 14, 2013, transcript, C3PO OHP.

181 Price, interview.

182 *NASA's Commercial Cargo Providers; Are They Ready to Supply the Space Station in the Post-Shuttle Era?: Hearing before the Subcommittee on Space and Aeronautics, United States House of Representatives*, 112th Cong., 1st sess., May 26, 2011 (statement of William H. Gerstenmaier, Associate Administrator for Space Operations), accessed September 30, 2013, *http://science.house.gov/sites/republicans.science.house.gov/files/documents/hearings/052611_Gerstenmaier%20Testimony.pdf*.

183 William H. Gerstenmaier, interview by Rebecca Wright, June 12, 2013, transcript, C3PO OHP.

184 Bretton Alexander, interview by Rebecca Wright, March 18, 2013, transcript, C3PO OHP.

185 Review of the U.S. Human Spaceflight Plans Committee (Public Meeting, Ronald Reagan Building and International Trade Center Amphitheater, Washington, DC, August 12, 2009), transcript, 69-70, accessed September 30, 2013, *http://www.nasa.gov/382774main_081209_DC_Transcript.txt*.

186 *Seeking a Human Spaceflight Program Worthy of a Great Nation: Final Report of the Review of U.S. Human Spaceflight Plans Committee* (Washington, DC: NASA, 2009), 57, accessed September 30, 2013, *http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf*. Emphasis added.

187 "Fiscal Year 2011 Budget Estimate," NASA, February 2010, accessed September 30, 2013, *http://www.nasa.gov/news/budget/2011.html*.

188 Marc G. Timm, interview by Rebecca Wright, June 12, 2013, transcript, C3PO OHP.

189 The National Aeronautics and Space Administration Authorization Act of 2010, Public Law 111–267, 111th Cong., 2d sess. (October 11, 2010), §§101 and 401, accessed September 30, 2013, *http://www.nasa.gov/pdf/649377main_PL_111-267.pdf*.

190 Price, interview.

191 When the COTS program was initiated the Commercial Crew & Cargo Program Office was under the Exploration Systems Mission Directorate (ESMD) at NASA Headquarters. After the retirement of the Space Shuttle in July 2011, the System Operations Mission Directorate (SOMD) merged with ESMD to form the Human Exploration and Operations (HEO) Mission Directorate under Associate Administrator William H. "Bill" Gerstenmaier.

192 Bruce A. Manners, interview by Rebecca Hackler, December 5, 2013, transcript, C3PO OHP.

193 Michael J. Horkachuck, interview by Rebecca Hackler, January 16, 2013, transcript, C3PO OHP.

194 Manners, interview.

195 Lori B. Garver, interview by Rebecca Wright, June 26, 2013, transcript, C3PO OHP.

196 Horkachuck, interview, January 16, 2013.

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198 Michael J. Horkachuck, interview by Rebecca Wright, November 6, 2013, transcript, C3PO OHP.

199 Horkachuck, interview, January 16, 2013.

200 Horkachuck, interview, November 6, 2012.

201 Bryan D. O'Connor, interview by Rebecca Wright, December 18, 2012, transcript, JSC Oral History Project, JSC History Collection, University of Houston-Clear Lake, Houston, TX; Jeffrey H. Cyphert, email communication to JSC History Office, July 24, 2013.

202 Mark D. Erminger, email communication to Commercial Crew & Cargo Program Office, November 20, 2013.

203 Horkachuck, interview, November 6, 2012.

204 Ibid.

205 David W. Thompson, interview by Rebecca Wright, June 3, 2013, transcript, C3PO OHP.

206 Kurt Eberly and Michael R. Pinkston, interview by Rebecca Wright, June 3, 2013, transcript, C3PO OHP.

207 Peter Capozzoli, interview by Rebecca Wright, January 16, 2013, transcript, C3PO OHP.

208 Horkachuck, interview, November 6, 2013.

209 Ibid.; Manners, interview.

210 Eberly and Pinkston, interview.

211 Timm, interview.

212 Manners, interview.

213 John E. Bretschneider (Booz Allen Hamilton), email communication to JSC History Office, September 25, 2013.

214 Horkachuck, interview, November 6, 2012.

215 Antonio L. Elias, interview by Rebecca Hackler, June 3, 2013, transcript, C3PO OHP.

Chapter 5

216 See David Giger, interview by Rebecca Hackler, January 15, 2013, transcript, Commercial Crew & Cargo Program History Project, JSC History Collection, University of Houston-Clear Lake, Houston, TX (hereafter cited as C3PO OHP).

217 Scott J. Horowitz, Commercial Orbital Transportation Services (COTS) Final Selection Statement, August 18, 2006, Attachment B, Commercial Crew & Cargo Program Office, Houston, TX.

218 Musk's confident persona, sometimes even described as "brash," has been credited as an instrumental factor in the company's success. For more on Musk see "Elon Musk, the Rocket Man with a Sweet Ride," *Smithsonian Magazine,* December 2012, accessed September 30, 2013, *http://www.smithsonianmag.com/science-nature/Elon-Musk-the-Rocket-Man-With-a-Sweet-Ride-179998091.html*.

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221 Michael J. Horkachuck, interview by Rebecca Wright, November 6, 2013, transcript, C3PO OHP.

222 Hans Koenigsmann, interview by Rebecca Hackler, January 15, 2013, transcript, C3PO OHP.

223 Tim Buzza, interview by Rebecca Wright, January 15, 2013, transcript, C3PO OHP.

224 Horowitz, Final Selection Statement, Attachment B.

225 "Falcon 1 Overview," Space Exploration Technologies Corp., accessed March 29, 2013, *http://www.spacex.com/falcon1.php*. This page was removed from the SpaceX website after the last date of access and is no longer publically available. For more on the first successful Falcon 1 launch, see Aaron Rowe, "SpaceX Did It — Falcon 1 Made it to Space," *Wired,* September 28, 2008, accessed September 30, 2013, *http://www.wired.com/wiredscience/2008/09/space-x-did-it/*.

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227 See "Falcon 9," Space Exploration Technologies Corp., accessed September 30, 2013, *http://www.spacex.com/falcon9*; "SpaceX Achieves Orbital Bullseye with Inaugural Flight of Falcon 9 Rocket," Press Release, Space Exploration Technologies Corp., June 7, 2010, accessed September 30, 2013, *http://www.spacex.com/press/2012/12/19/spacex-achieves-orbital-bullseye-inaugural-flight-falcon-9-rocket*.

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242 Alan Marty, interview by Rebecca Hackler, January 18, 2013, transcript, C3PO OHP.

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244 John E. Bretschneider (Booz Allen Hamilton), email communication to JSC History Office, June 13, 2013.

245 Michael J. Horkachuck, email communication to Commercial Crew & Cargo Program Office, November 17, 2013.

246 Horkachuck, interview, November 6, 2012. In interviews with engineers at SpaceX, employees denied such fears, always expressing confidence in NASA's commitment to the partnership. Koenigsmann, interview; Peter Capozzoli, interview by Rebecca Wright, January 16, 2013, transcript, C3PO OHP.

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249 Shotwell, interview. The Associate Administrator of NASA's Human Exploration and Operations Directorate disagreed, stating the company did not believe those tests were necessary. William H. Gerstenmaier, interview by Rebecca Wright, June 12, 2013, transcript, C3PO OHP.

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259 Horkachuck, interview, November 6, 2012; Valin B. Thorn, interview by Rebecca Hackler, December 17, 2012, transcript, C3PO OHP.

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261 Geoffrey L. Yoder, Selection Statement for Commercial Crew Development (Announcement Number JSC-CCDev-1), December 8, 2009, 19–20, Commercial Crew & Cargo Program Office, Houston, TX.

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13. ABSTRACT *(Maximum 200 words)*
From 2006 to 2013, the Commercial Orbital Transportation Services (COTS) program administered by the Commercial Crew & Cargo Program Office (C3PO) at the Johnson Space Center endeavored to stimulate U.S. commercial space transportation capabilities by pursuing a new way of doing business with industry. C3PO collaborated with a team of attorneys, procurement specialists, and even a venture capitalist to formulate and implement a new form of funded Space Act Agreement (SAA) based on the Agency's "Other Transaction" Authority. In August 2006, NASA selected SpaceX and Rocketplane Kistler as its first COTS partners. However, NASA terminated the agreement with Rocketplane Kistler due to the company's funding issues, and in February 2008 the Agency selected Orbital Sciences Corporation as its new industry partner. NASA worked with SpaceX and Orbital to meet the financial, programmatic, and technical milestones of their funded SAAs—milestones that would culminate in the development of new, commercially-owned transportation services to the International Space Station. The COTS program helped to realize the vision of cost-effective, U.S. space transportation capabilities and a successful partnership with industry.

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